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University of New Brunswick

EVALUATION OF AND OPERATING EXPERIENCE WITH A HEAT HARVESTER GREEN CHIP PRE-FURNACE

1985 - 1986

DSS File No. 24ST.23216-4-6054

90-00383/

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Submitted to:

Renewable Energy Division
Energy, Mines and Resources Canada
Ottawa, Ontario

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1987 06 08

ABSTRACT

Tests were conducted on a fully automatic wood-chip-fuelled combustion system designated as model TB500H and manufactured by the Heat Harvester Corporation, Carrboro, North Carolina. The unit is rated at 90 to 180 kW (300,000 to 600,000 btu/h) output, depending upon the fuel used, but was found to be limited to about 70 kW (250,000 btu/h) gross energy input when fuelled with dry hardwood chips.

Attempts to use the appliance for routine heating in a house were not successful for many reasons. Automatic ignition did not occur reliably and ash removal did not take place as intended. Combustion chamber and fuel-feed components failed due to inability to endure the temperatures to which they were exposed and to failure to allow for thermal expansion in their design. Fuel feed from the system fuel hopper was unreliable and the handling system in the hopper required additions to overcome irregular fuel delivery rates due to funnel flow, piping and bridging in the fuel. Control system components failed and required expensive repairs, and the control system itself required modification in order to obtain proper operation.

An automatically controlled, mechanical fuel handling system incorporating a flexible auger was arranged to move wood chips from a ground-level storage bin and into the combustion system fuel hopper. Because of the difficulties experienced with operation of the combustion system, the bin-to-hopper fuel handling system was not tested under routine, long-term, relatively unattended conditions; however, it appears to work as intended.

SOMMAIRE

Des essais ont été effectués avec un appareil de combustion entièrement automatique alimenté aux copeaux de bois, désigné comme le modèle TB500H et fabriqué par la Heat Harvester Corporation, de Carrboro, Caroline du Nord. Le taux de rendement variait de 90 à 180 kW (300 000 à 600 000 btu/h) selon le combustible utilisé, mais il était limité à environ 70 kW (250 000 btu/h) lorsqu'alimenté avec des copeaux de feuillus secs.

L'appareil n'a pu servir à chauffer normalement une habitation résidentielle pour plusieurs raisons. Le système d'ignition automatique n'était pas fiable et l'élimination des cendres ne s'est pas réalisée comme prévu. La chambre de combustion et le dispositif d'alimentation en combustible n'ont pu fonctionner normalement en raison des températures élevées auxquels ils étaient exposés et du manque d'expansion à la chaleur, caractéristique qui n'avait pas été prévue dans leur conception. La trémi d'alimentation ne fonctionnait pas de façon satisfaisante et le dispositif en place a dû être modifié pour éviter le phénomène d'irrégularité causé par l'effet d'entonnoir, de pont et de trouées qui empêchait le combustible de descendre dans le fond de la trémie. Les composants du dispositif de commande ont fait défaut, ce qui a entraîné des réparations coûteuses, et le dispositif lui-même a dû être modifié pour fonctionner de façon satisfaisante.

Un dispositif mécanique à commande automatique, incorporant une trémie flexible, a été mis en place pour permettre l'acheminement des copeaux à partir du systéme d'entreposage au niveau du sol jusqu' à la trémie d'alimentation de la chambre de combustion. Etant donné les difficultées qui ont nui au fonctionnement du système de combustion, le dispositif d'acheminement du combustible jusqu' à la tremie n'a pu faire l'objet d'essais prolongés en situation normale sans grande surveillance, mais il semblait fonctionner comme prévu.

ACKNOWLEDGEMENTS

Mr. Keith Pike helped conduct some of the preliminary setting tests, the fuel characterization tests and some of the emission tests. Mr. S. Bowser assisted with diagnosis of the control system operational problems and circuit modification to overcome those problems, and also helped to determine the nature of the failure in the temperature control device. Mr. A. Knappe provided valuable advice and assistance with thermocouple application and mounting. Mr. W. Edgar designed the high temperature connecting duct between the combustion system and the boiler, and also the original ash auger drive mechanism. Mr. K. Smissaert designed and installed the revised ash handling system and the fuel flow-promoting system. Mr. D. Carr fabricated the revised ash handling system. Dr. R. Douglas suggested the scheme whereby chips could be recovered from the bulk bin, and Mr. R. May designed parts of the bin-to-hopper fuel-handling system and, with Mr. Smissaert, installed the system and made the modifications required to the bin in order to accommodate the various conveyors. Mr. Gilmour of Gilmour Fire Protection Ltd., Fredericton, N.B. generously provided sprinkler heads for use in the revised fire extinguishing system fitted to the Heat Harvester. The author is greatly indebted to these individuals for their suggestions and help in the conduct of this project.

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1 INTRODUCTION

1.1 Objectives of Test Program

In general terms, the objectives of the test program detailed in this report were to observe and to report upon the performance of, and all problems relating to, a Heat Harvester green chip pre-furnace. As originally planned, the performance evaluation was to take place over one heating season, that of 1984-85.

Specific objectives were as follows:

1. To find a suitable residence or small commercial building to receive and utilize the equipment, and to make the necessary arrangements with the owner.
2. To select, purchase and install all necessary equipment, including instrumentation to permit measurement of fuel input, energy output and system efficiency.
3. To arrange for a suitable fuel supply, and for fuel storage and handling.
4. To arrange for routine monitoring of the performance of the installation relative to meter readings and preparation of a log of events.
5. To solve all problems beyond the ability of the householder or building occupants, especially those problems associated with the nature of the fuel supply, or with storage and

handling problems.

6. To recommend changes to either the equipment or operating procedures to improve efficiency and/or to reduce emissions.

1.2 Equipment description

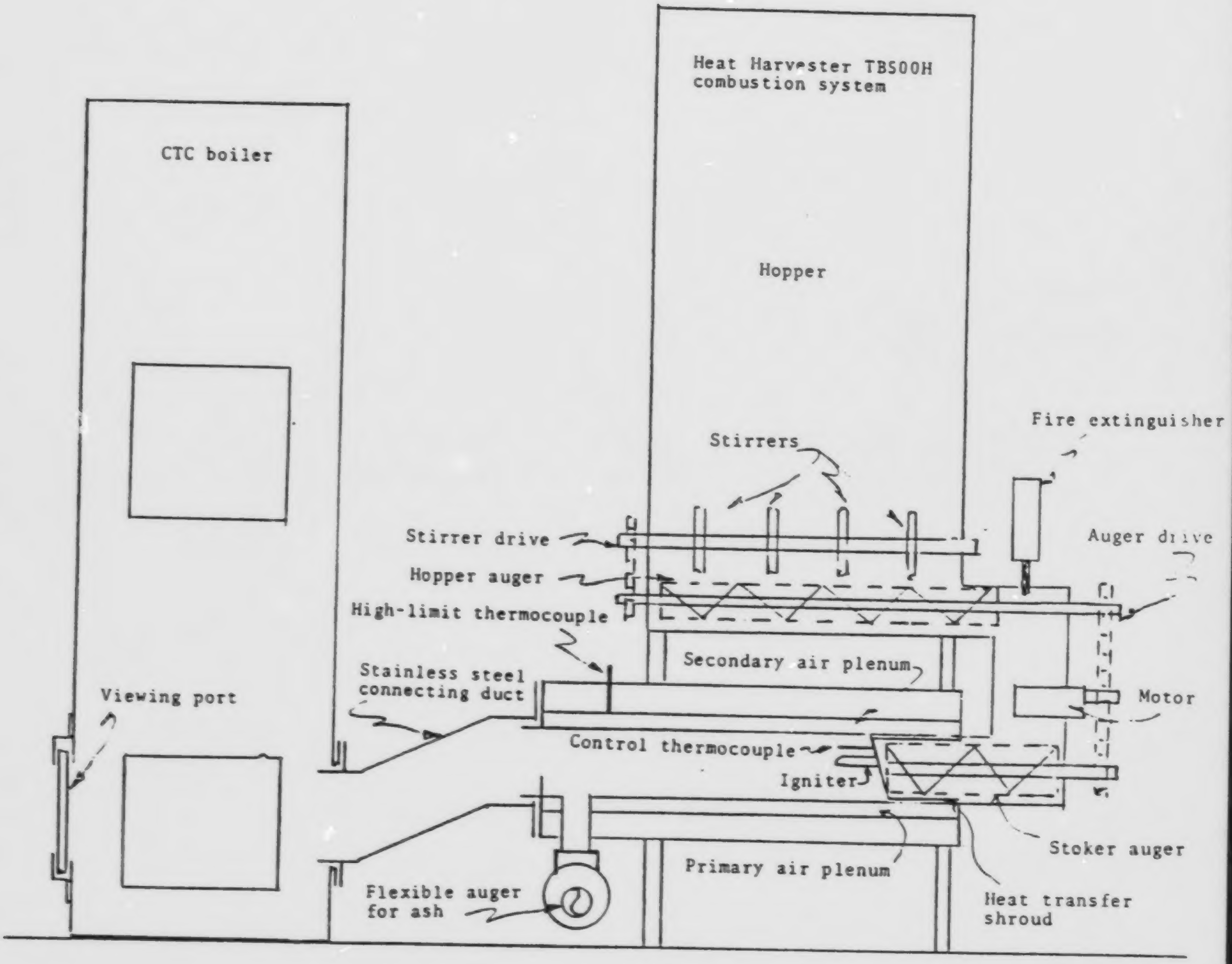
The combustion system was designed and fabricated by the Heat Harvester Corporation, Carrboro, North Carolina, and is designated as Heat Harvester model TB500H. The Heat Harvester is intended to burn a variety of fuels including:

dry wood chips
green wood chips
wood pellets
wood cubes
wood shavings
grass pellets
peat pellets
paper waste cubes
nut shells
nut hulls
pelletized agricultural wastes.

The appliance incorporates a mechanically-stoked, horizontal tunnel burner and is equipped with various controls intended to provide automatic ignition of the fuel, removal of ash, rapid burn-out of remaining coals on shut-down, and a clean burn when running. A manually-filled hopper provided as part of the device holds a supply of fuel sufficient for several hours of continuous operation; the actual running time between refills depends upon fuel quality and the heat output rate at which the burner is being operated. The Heat Harvester is intended to be coupled to a hot air furnace or a hot water boiler which serves as the heat exchanger.

1.2.1 Technical description

The combustion chamber consists of a horizontal stainless steel cylinder having an inside diameter of 254 mm (10 in). The cylinder is about 800 mm (32 in) long. Several rows of holes through the cylinder wall admit combustion air which can be directed through the lower half of the cylinder (primary or under-fire air), or through the upper half of the cylinder (secondary or over-fire air). A second stainless steel cylinder of about 305 mm (12 in) diameter surrounds the perforated cylinder, and serves as an air plenum. The plenum is divided into an upper and a lower section by two horizontal baffles which are placed between the cylinders and run the length of the combustion chamber. The forced draft fan blows air into the space between the two cylinders, and the amount of air supplied under or over the fire is controlled by dampers at the air inlet flange between the combustion chamber assembly and the forced draft fan. The


Heat Harvester TB500H
combustion system
CTC boiler
Hopper
Fire extinguisher
Stirrers
Stirrer drive
Auger drive
Hopper auger
High-limit thermocouple
Secondary air plenum
Stainless steel
connecting duct
Viewing port
Motor
Control thermocouple
Igniter
Stoker auger
Primary air plenum
Flexible auger
for ash
Heat transfer
shroud

Heat Harvester and CTC boiler.
General arrangement.
Fig. 1.2.1

combustion chamber assembly is insulated with 50 mm (2 in) of ceramic fibre insulation wrapped, in turn, with a further layer of mineral wool, and is then enclosed in a sheet steel jacket.

Fuel is taken from the 0.6 cu.m (21.5 cu ft) hopper located above the combustion chamber assembly and is pushed into the rear end of the combustion chamber by a system of augers; the auger in the fuel hopper delivers fuel to a transfer box where the fuel drops about 400 mm (16 in) to a second auger which carries it into the combustion chamber. On a call for heat, the augers run for a pre-determined time as set on timer T1. At the end of this time, (which is set based upon operating experience with the fuel and the firing rate being used) the fuel supply system is turned off. The fuel is ignited by an electrically operated heating element, and when combustion chamber temperature exceeds a pre-set value (readily set on control TB1), the ignition element is turned off, the combustion air supply is started, and the fuel feed system is turned on. The system continues to operate until the demand for heat has been satisfied, at which time the fuel supply system stops, and the air supply is maintained for a pre-set time (timer T2) in order to burn out the fuel remaining in the combustion chamber. If, during operation, the temperature of the stainless steel combustion chamber should exceed a safe limit, a temperature control (control TB2 - adjustable between 760C and 980C (1400F and 1800F)) interrupts the fuel feed system until the temperature drops by about 110C (200F). In the event that a call for heat should arise while the combustion chamber is still hot enough to ignite incoming, fresh fuel, then the system starts directly without operating the ignition element. If, for any reason, the combustion chamber temperature drops below the pre-set value used to control the ignition element (TB1), then a cold-start ignition sequence, as outlined earlier, is initiated until re-ignition is obtained. Should ignition not be obtained within a time period of up to an hour (set on timer T3), then the control system turns all burner systems off and provides a line voltage (120 v) signal at a convenient terminal; this can be used to operate an alarm or to turn on a back-up heating system.

Gases leave at the hot end of the combustion chamber through a custom fabricated, stainless steel transition duct about 330 mm (13 in) long, insulated with ceramic fibre, and clad with an aluminum jacket. The duct projects through a port cut into the ash pit of a model 453B hot water boiler manufactured by AB CTC, Ljungby, Sweden. The port is a standard feature on this boiler, and was originally used to admit the grate assembly of a wood-chip fuelled stoker. Heat from the boiler can be transferred to the house and/or to domestic hot water (via a conventional coil installed in the boiler), or (in season) can be transferred to an outdoor swimming pool via a water-to-water heat exchanger.

A port 60 mm by 215 mm (2.5 in by 8.5 in) is located in the base of the combustion chamber immediately adjacent to the gas exit flange in order that ash can be discharged. A 38 mm (1.5 in) flexible auger turning at about 3 rpm and running in an 80 mm (3.25 in) diameter steel conduit collects ash from the port and transfers it to a sealed 20 l (5 gallon) steel container. The ash auger drive motor is connected to run whenever the fuel feed auger system operates.

1.2.2 Field assembly - mechanical

The Heat Harvester was received semi-assembled. Three major sub-assemblies had to be fitted together, and then several smaller components attached as required in order to complete the mechanical assembly of the appliance.

The largest component is the hopper/frame unit. This is 1675 mm (66 in) high, 660 mm (26 in) long, and 940 mm (37 in) wide overall. To this, the 845 mm (33 in) long, caster-equipped legs were bolted. The legs can be attached in such a way as to vary the overall height of the appliance in order best to couple it to whatever boiler or furnace with which it is to be used. In this case, the legs were attached to obtain the lowest possible height because this both suited the boiler connection, and provided the greatest clearance between the top of the hopper and the ceiling in order to accommodate fuelling.

The combustion chamber assembly was then fitted to the hopper/frame. This assembly is a rectangular device 815 mm (32 in) long and 435 mm (17 in) in both height and width. It is carried directly below the fuel hopper and is supported at the rear (the fuel input end) where it rests on a piece of steel angle welded to the hopper/frame unit, and is otherwise free to move both longitudinally and laterally, presumably in order to accommodate thermal expansion. The hot end of the combustion chamber assembly is suspended from two horizontal, steel struts which project forward from the hopper/frame unit at the base of the hopper, and which have two slots cut in them. Two studs which protrude from the top of the combustion chamber assembly slide into the slots, and washers and nuts, fitted to the studs, hold the studs in place in the slots. Fine adjustments in combustion chamber height can be made by tightening or loosening the nuts; the slotted arrangement permits longitudinal movement and, as with the rear support, presumably is intended to allow thermal expansion. It was necessary to increase the width of the slots in the hot-end support struts by using a power grinder because, as provided, the slots were too narrow to admit the mounting studs on the combustion chamber assembly.

With the combustion chamber in place on the hopper/frame, it was possible to fit the auger/drive assembly. To accomplish this, an outboard bearing - supplied by the manufacturer - had to be installed on the front wall of the hopper; this bearing carries one end of the hopper fuel-feed auger, and was fitted without difficulty using pre-drilled holes and the mounting hardware supplied. Installation of the auger/drive should have been straightforward, but was complicated somewhat because the centre distance between the two auger tube extensions on the auger/drive did not match that between the openings in the rear of the fuel hopper and the rear of the combustion chamber into which the extensions were supposed to insert; also, the opening into the rear of the combustion chamber was too tight and so did not admit the stoker auger tube-extension even when the two were subsequently test-fitted off the hopper/frame assembly. In order to permit assembly of the auger/drive to the combustion chamber, it was necessary to grind off much of a bead of welded material that projected inside the combustion chamber auger attachment port. With connection between the auger/drive and the combustion chamber now possible, test fitting of the auger/drive to the assembled hopper/frame and combustion chamber was possible. Because it was necessary, in effect, to reduce the centre distance between the hopper and combustion chamber ports, and because it was physically impossible to move the combustion chamber any closer to the hopper, the only available option was to grind material away from the bottom inside edge of the hopper port until sufficient clearance was obtained to permit an easy, non-forced, fit. This required many trial assembly and disassembly operations until an acceptable fit was obtained. After the auger/drive unit was in place, it was discovered that the four attachment holes between the hopper wall and the bolt flange on the hopper auger tube extension were not in alignment, and so it was necessary to drill these out in order to insert and fasten bolts in place. This completed the assembly of the major mechanical components.

It remained to attach the control panel, the forced-draft fan, and the fire extinguisher. The first two items were mounted without difficulty; however, the fire extinguisher could not be mounted on the bracket provided because, even though the bolt holes were in the correct place, the wall of the hopper interfered severely with the body of the fire extinguisher. It was necessary to design and fabricate an adapter plate to permit mounting the extinguisher onto the support strut provided for it. The nozzle of the self-actuated extinguisher projected into a 2 in threaded coupling welded onto the top of the hopper auger tube, and the space between the nozzle and the inside of the coupling was covered by a crude, two-piece, wooden plug held together by a velcro-fastened nylon strap - all provided by the manufacturer. As directed by the manufacturer, all joints were made air-tight using a high-temperature silicone rubber sealant supplied with the equipment.

1.2.3 Field assembly - electrical

The Heat Harvester was supplied without power (120 volt AC and 90 volt DC) wiring of any kind, and without openings, connectors or junction boxes to accommodate power wiring. In order to make the unit operable, it was necessary to interconnect all the various components. A labled terminal block was provided in the control panel, but holes or knock-outs through the wall of the control panel, required in order to make wiring connections, simply did not exist. Circuits were required between the control panel and the following:

incoming 120 volt AC supply
control signal to indicate a need for heat (120 volt AC)
supply to ignition element (120 volt AC)
supply for forced-draft fan (120 volt AC)
supply for ash auger drive motor (120 volt AC)
control signal for back-up heating system (120 volt AC)
supply for fuel-feed auger drive motor (90 volt DC)
supply for induced-draft fan (120 volt AC)

and in addition, connections were required between the two thermocouples used to sense fire and combustion chamber wall temperatures and their respective controls within the control panel.

In order to complete the electrical connections to devices on the Heat Harvester and also to provide the incoming power supply and control signal, 12 gauge, thermoplastic-sheathed, armoured, flexible cable type TECK90 was used along with the appropriate connectors. The 7/8 in holes in the control panel wall for the connectors were made using a Greenlee hole punch in order to avoid the possible damage to adjacent control wiring that could arise using other types of hole cutter. Junction boxes were acquired and installed on the rear of the combustion chamber to serve the 90 volt DC auger motor and the 120 volt AC igniter supplies; TECK90 cable was run from the control panel to these junction boxes. The leads from the DC gearmotor were encased in heat-shrinkable tubing and were taken to one junction box where they were connected to the TECK cable. Connections between the igniter and its junction box were made using type HPN heater cord, which has a maximum allowable temperature of 90C.

For connecting the circuits for the ash auger drive, the induced-draft fan and the back-up heating controls, single outlet, 120 volt, twist-lock receptacles were installed through the left side of the control panel; the 1-3/8 in holes for these were also made using a Greenlee punch. The receptacles were wired as follows:

ash auger - energized whenever the fuel feed augers operate induced-draft fan - energized on a call for heat

back-up control - connected to the auxiliary terminals in the control panel

1.2.4 Field assembly - control system

Thermocouple connections were made using special extension wire suitable for type K (chromel-alumel) thermocouples. In order to permit rapid replacement of the thermocouples and also to connect instrumentation to aid in diagnostic testing when required, type K panel-mounted connectors were installed through the control panel walls; type K plugs installed on the thermocouple lead wires could then either be plugged into the control panel connectors or into independent instruments in order to obtain actual thermocouple temperatures. The ability to disconnect quickly the control thermocouples also simplified various aspects of appliance calibration by making it possible, for instance, to over-ride the auger drive interlock circuit and so as to measure fuel feed rates despite lack of fire in the combustion chamber.

The type K thermocouple supplied to measure combustion chamber temperature was 450 mm (18 in) long and 3 mm (1/8 in) diameter. It was fitted with integral lead wires emerging directly from its stainless steel sheath. The thermocouple was inserted through a compression fitting in the rear surface of the combustion chamber and located (by the manufacturer) about 40 mm (1.5 in) below the ignition element. The thermocouple was installed so that its tip was directly below that of the ignition element.

The thermocouple used to monitor combustion chamber wall temperature was supplied already installed. It was noted that the lead wires emerging from the combustion chamber jacket did so directly beneath a steel frame member of the hopper/frame assembly; this caused the wires to be bent quite sharply and to be pinched somewhat as they passed beneath the frame, nevertheless, an initial electrical check indicated that the thermocouple and its wiring were undamaged.

1.3 Burner-to-boiler connection

A transition duct was designed and fabricated to take hot combustion gasses from the 255 mm (10 in) diameter combustion chamber port to the 215 mm wide by 145 mm high (8.5 in by 5.75 in) port into the boiler. The duct was equipped with a flange drilled to mate with the bolt pattern on the outlet face of the combustion chamber, and was also flanged at the boiler connection port in order to support a fibreglass gasket at the boiler. The duct was designed so as to permit a sliding fit between it and the boiler port in order to accomodate thermal expansion. The duct was fabricated from 11 gauge, type 309 stainless steel as suggested by the burner manufacturer, and was wrapped with a 50 mm (2 in) thick layer of ceramic fibre insulation. An aluminum jacket was then fabricated to fit over and to protect the insulation. A stainless steel thermocouple compression mount was subsequently fitted to the top of the duct in order to permit insertion of a thermocouple to measure combustion gas temperature at the centre of the combustion chamber outlet port.

The boiler port was modified by welding a 25 mm (1 in) wide external flange around it. This provided a surface against which the fibreglass gasket around the transition duct could seal.

A 3 mm (1/8 in) thick sheet-asbestos gasket was cut to fit the outlet flange of the Heat Harvester combustion chamber, and the transition duct was bolted into place on the combustion chamber. When the Heat Harvester was rolled into position beside the boiler, the boiler end of the duct fitted precisely into the boiler, and the gasket on the duct was compressed between the flanges on the boiler and on the duct.

1.4 Ash handling system

The Heat Harvester incorporates an ash discharge port at the bottom of the combustion chamber immediately inside the combustion gas outlet port. The ash port is approximately 50 mm by 200 mm wide (2 in by 8 in). A 50 mm (2 in) high barrier downstream of the ash port is intended to divert ash moving along the floor of the combustion chamber and to ensure that it falls through the port. To collect ash that falls through the port, some sort of system is required. Presumably, if the burner installation is such that there exists sufficient space under the combustion chamber, then a steel container arranged to seal tightly to the ash port outlet flange would serve the purpose. With the arrangement involved in this installation, the bottom of the combustion chamber assembly was about 125 mm (5 in) above floor level, and this resulted in the ash port outlet flange being 100 mm (4 in) above floor level.

Given the limited space available, and in anticipation of handling a fine, light, powdery material, an auger system was designed that used a 38 mm (1.5 in) centreless, flexible steel auger about 3 m (10 ft) long running in a 50 mm (2 in) steel conduit. The conduit was coupled to the ash port outlet by a specially designed adapter, and this was clamped to the flanges along both sides of the outlet using small self-locking pliers. The conduit was formed so as to run 610 mm (2 ft) horizontally from the ash outlet port and then bend at a 610 mm (2 ft) radius, following which it ran a further 1220 mm (4 ft) along a straight section inclined at about 30 degrees to the horizontal so as to move ash to the top of a sealed 45 gallon oil drum which served as the ash collector. A 50 w (1/15 hp) gearhead motor having an output shaft speed of 28 rpm was arranged to drive the auger; the motor was connected to run whenever the Heat Harvester fuel feed system was in operation.

1.5 Back-up heating system interconnection

1.5.1 Electrical

The hot water heating system installed in the house is supplied by a 20 kW Chromalox electric boiler (model EDB-20-2); the boiler has been down-rated to 10 kW by disconnecting two of its four heating elements because it tended to cycle overly frequently on its high-limit control. The Chromalox boiler requires that the water circulating pump be connected to its control system to ensure that water is being circulated before the electrical power is supplied to the heating elements following a call for heat. Also, the Chromalox control system requires that an external single pole, single throw switch (wall thermostat switch, or end-switch in a zone control valve) be closed in order to signal a need for heat. Because it was desired to use the Chromalox boiler as an automatic back-up heat source in the event that the Heat Harvester should fail, and also as the sole source of heat during times when the Heat Harvester was either removed from the heating system or in use for heating an in-ground swimming pool, several additions had to be made to the Chromalox control circuit.

The Heat Harvester control system is arranged to provide a 120 volt supply across two points on the terminal block inside the control panel if the combustion system should fail for any reason. This voltage, when supplied by the Heat Harvester, remains on continuously until the Heat Harvester controls are manually reset. A 120 volt relay (R5) was installed on the Chromalox boiler control panel (using existing mounting holes), and was wired so that it would operate to close a set of contacts whenever the Heat Harvester provided the 120 volt system-failure signal. A second 120 volt relay (R4), also installed on the Chromalox control panel, was wired to operate whenever the electrical supply is turned on to the Chromalox boiler, and one or more zone control valves operates due to a call for heat from the room thermostat controlling the valve. When R4 operates, it closes two sets of contacts; one set is connected directly to terminals identified as SW1 and SW2 on the Chromalox boiler, and the contact closure across these causes the circulating pump to run. The second set of contacts is wired in series with those of R5 and the circuit thus created is connected to terminals T1 and T2 on the Chromalox boiler; provided both R4 and R5 are energized (thus indicating a call for heat together with failure of the wood chip system), the low voltage thermostat circuit on the Chromalox boiler is completed, and the Chromalox boiler heats up normally. If the wood chip system is functioning normally, when a call for heat is received the zone control valve in question opens thus causing R4 to operate and the circulating pump to run; the Chromalox boiler does not operate because R5 is not energized and so the circuit to Chromalox terminals T1 and T2 is not complete. Whenever it is desired to operate the Chromalox boiler as the sole source of heat, a manually-operated switch wired across the switch contacts on R5 is closed; this in effect simulates operation of R5 and permits completion of the circuit to terminals T1 and T2 whenever R4 operates due to zone valve operation on a call for heat. The Chromalox wiring diagrams appear in Appendix IV.

1.5.2 Mechanical

In order to accommodate the various operating modes outlined above, a piping system had to be provided that would permit operation of the CTC boiler (heated by the Heat Harvester) while in series with the Chromalox unit or that, with a change in valve settings, would permit independent operation of the two boilers.

For normal operation of the wood chip heating system with availability of the Chromalox boiler for back-up purposes, valves can be set so that the circulating pump supplies cool water from the various heating loops directly to the CTC boiler. The water then flows to the Chromalox boiler, and thence back to the heating loops requiring heat. It would have been possible, by using solenoid-controlled valves for example, to arrange a piping system that would automatically by-pass the CTC boiler when electric heating was in use; such a system would have the advantage of avoiding the heat loss associated with keeping the CTC boiler hot. Because the CTC boiler is installed in a garage, there exists a danger of its freezing should the garage doors be left open during a particularly cold period; to avoid this possibility, the decision was taken to accept the added energy cost associated with heating the CTC boiler when using electric heat.

At times when the CTC boiler is being used for test purposes, it is possible to transfer the heat it produces to an in-ground swimming pool. This is done by setting valves so that the hot water flow from the CTC boiler is directed to a concentric pipe, counter-flow, water-to-water heat exchanger; boiler water is cooled as it flows through a 25 mm (1 in) copper pipe, and pool water is heated as it passes through a 50 mm (2 in) copper pipe through the centre of which the 25 mm pipe has been fitted. A circulating pump installed at the relatively cool, outlet end of the heat exchanger forces boiler water through the heat exchanger. At times when the CTC boiler is connected to the heat exchanger, house heat can be provided by the Chromalox boiler. A schematic diagram of the piping arrangement is shown in Appendix IV.

Domestic hot water (DHW) can be supplied from either a tankless coil (water-to-water heat exchanger) delivered with and fitted inside the CTC boiler, or can be supplied by a well-insulated, 270 l (60 Imp gal), electric hot water heater. Provision has not been made for automatic transfer to electric heat for DHW production; at times when the wood chip heating system fails or is connected to the pool heat exchanger, it is necessary to close one valve on the CTC DHW coil inlet, and open another on the inlet to the electric DHW tank. In practice, the electric DHW tank is maintained hot at all times, and so a supply of DHW is immediately available should it be required. Installation of the electric DHW tank made it possible to assess operation of the wood chip heating system when supplying space heat and DHW, space heat only, or DHW only.

1.6 Draft inducer installation

Early experience with the Heat Harvester revealed that, especially in relatively warm weather when chimney draft was low, a problem existed with smoke leakage from the Heat Harvester and the boiler whenever the forced draft fan on the Heat Harvester started. In order to overcome the problem, a Tjernlund Model 1L draft-inducing fan was ordered and installed in the chimney connector duct close to the point where it enters the masonry chimney. The model 1L draft inducer is intended for installation on a duct having a diameter between 230 mm and 460 mm (9 in to 18 in), and so had to be modified somewhat to permit its installation on the surface of the existing rectangular duct; this involved flattening the pre-gasketted flanges on the inducer, and then drilling suitable mounting holes in the flanges. A rectangular opening was cut in the upper surface of the duct (3 mm (1/8 in) thick material), and holes were drilled and tapped to accept the mounting bolts used to attach the draft inducer. The flanges were coated with a heat-resistant, clear silicone sealant prior to installation of the inducer on the duct. This installation deviated from that recommended by the manufacturer in that, according to the manufacturer, the inducer should have been mounted on the bottom of the duct to avoid creating a heat trap in the inducer. The top surface mounting was chosen in order to avoid creating openings through which creosote, if any, might leak, and to avoid possible accumulations of creosote and fly-ash in the inducer; the top surface mounting was also considerably easier to achieve, and resulted in both better protection of the inducer, and better access for wiring and maintenance than would have been the case had bottom surface mounting been used. Operational experience with the inducer has not revealed any heating problems; at times when the boiler is used without operating the inducer, the inducer housing has been very cool, probably due to air flowing into it through the motor shaft opening. The draft inducer was connected to operate whenever the boiler aquastat indicated a need for heat; this resulted in a negative pressure being developed in the combustion chamber, and eliminated the smoke leakage problem under all normal circumstances. On satisfaction of the boiler aquastat, the draft inducer would shut down despite continued operation of the Heat Harvester as the forced draft fan on the burner continued to run in order to burn up any remaining fuel quickly and cleanly. Because under such circumstances the chimney had become well heated, chimney draft was well developed, negative combustion chamber pressure was maintained, and there was no tendency for smoke leakage.

Two problems arose with the Tjernlund 1L draft inducer. First, the inducer was found to be over-sized for the installation; it was able to develop a draft in excess of 60 Pa (0.25 in water), although this in itself was not a problem because draft in the boiler could be regulated using the damper in the boiler's flue outlet. Secondly, the noise generated by the inducer, while tolerable during daytime operation, was unacceptable at night - especially because the boiler and its associated equipment is located directly beneath the bedroom area of the house. Because of both these problems, it was decided to install the smallest available Tjernlund draft inducer, a model DJ-3. This unit was not readily available and so, in order to expedite work, a model D-3 was accepted instead. The smaller D-3 model inducer, mounted in place of the original unit using an adapter plate, was found to be able to develop a draft of about 25 Pa (0.10 in water) and was also very quiet.

1.7 Electric hot water system

A requirement of the test program was to operate the solid fuel fired boiler to supply space heating only on alternate weeks, and to supply both space heating and domestic hot water during the intervening weeks. The two operating modes thus used would permit assessment of the Heat Harvester/boiler combination while carrying a space heating load, which tends to vary gradually with meteorological conditions and the occupants' requirements, and to compare this with the same system when carrying the DHW load also, which tends to be marked by infrequent, relatively brief periods of high heat demand.

The house used for test purposes was not equipped with a separate DHW heater, and so an electric heating tank was obtained. The intent was to make direct comparisons between energy supplied by electricity and by wood chips to meet the same DHW heating load; this was to be done so as to make the fairest comparison possible and to not place the electric heating system at a disadvantage. A rental tank of the type offered by the local electrical utility was not considered suitable for test purposes because of the relatively low level of insulation installed on such tanks; this was expected to lead to higher than necessary electrical energy consumption. Therefore a well-insulated, 270 l (60 gal) tank, the Sears Power Miser Mark 3, was purchased and installed.

The plumbing was arranged so that the tank was connected in parallel with the DHW heat exchanger in the boiler. Hot water could be drawn from either source by opening the cold water supply valve to the desired source and closing that to the other. An anti-thermosiphoning trap was arranged in the hot water outlet piping and all piping was fitted with 15 mm (5/8 in) thick polyethylene insulation in order to reduce stand-by heat loss. A 100 amp watthour meter was installed to monitor electrical energy used to operate the tank, and an integrating energy meter (Rho Sigma, Inc., Model RS805) was installed to measure both the total quantity of water heated and the thermal energy in the hot water supplied by the tank.

1.8 Instrumentation

All electrical energy supplies to equipment used in the heating system were monitored by watthour meters. Thermal energy outputs to space heat and to DHW were monitored by integrating energy meters. Totalizing water meters were installed on both DHW heating systems. Temperature sensors were installed in thermowells on the inlet and outlet pipes to both DHW heaters and on the space heating system connections at the CTC boiler. Temperature sensors were also installed at each of the three thermostats used to control temperature in the living area zones in the house, in the boiler room, on various surfaces of the boiler and the burner, and one sensor was mounted outdoors. A totalizing timer was connected to run whenever the fuel feed auger operated. Provision was made to record the time-of-day and duration of operation of the fuel feed auger, burner ignition system, back-up heating system, and space heating water circulating pump. Of the foregoing, all instruments except the temperature sensors and the time-of-day/duration recorders could be read manually; daily records were made of readings taken from all readable instruments. All instruments were modified in order to permit their outputs to be logged by a data acquisition system which was used to collect information from all instruments, sensors and timers on an hourly basis.

1.8.1 Data acquisition system

An E-MAC data acquisition system designed and built by Holman

Electronic Controls Ltd., Fredericton, was selected for data logging. The system was equipped with 16 analogue channels primarily for use with temperature sensors, and 16 digital channels. Of the latter, four were specially modified to log the starting and stopping times of the devices connected to them, while the remainder were used to collect information supplied as a low-voltage, square-wave pulse obtained from watthour, integrating energy and water meters.

1.8.2 Output

The system was programmed to read all analogue sensors once every minute and to accumulate the total of all such readings in a one hour time period. On the hour, the instantaneous reading from each sensor and also the accumulated totals were recorded on magnetic tape. This permitted determination of both the hourly temperature at each of the sensors and also the average temperature at each sensor - the average being obtained by dividing the recorded total by sixty during subsequent data reduction. Digital (pulse) data was treated in a somewhat similar manner, with the pulses received from each meter during an hour being totalized and the total being recorded at the end of each hour. Conversion of the total number of pulses per hour recorded from any given meter to a meaningful physical quantity required division of the total by, for example, the number of pulses per liter of water produced by a water meter - a value obtained from calibration tests performed on the meter. Starting and stopping times for the various devices (motors, heating elements) were obtained via an optical transducer connected to the electrical supply for each; when any device started, the signal being produced by its transducer was detected and the minute and second at which the signal appeared was recorded. When the device was de-energized, the disappearance of the signal from its transducer was detected, and again, the time recorded. The entire record of all starting and stopping times, each identified by its channel number, was recorded hourly on magnetic tape. Typical system output is shown in Appendix XI.

1.8.3 Sensor modification and calibration

1.8.3.1 Temperature sensors

The silicone diode temperature sensors supplied with the data acquisition system were calibrated by immersing them in an insulated flask filled with a well-stirred mixture of distilled water and crushed ice. Then trimming potentiometers provided for the purpose with each sensor were adjusted to obtain an indicated output on the system display of precisely 0C. The sensors were known to respond linearly to temperatures over a range from -50C to 125C within 0.5C, and the performance of each at room temperature was confirmed by comparing the displayed temperature with that measured using a laboratory thermometer of known accuracy.

1.8.3.2 Watthour meters

The watthour meters were modified by installing a small light source and photo-cell under the rotating disk in each; a strip of non-reflective electrical tape was attached to the underside of the disk so that, on each disc revolution, the tape interrupted light being reflected back to the photo-cell from the source. The circuitry in the system interpreted the variation in output from the photo-cell due to each such interruption as a single count, hence accumulating one count for each disk revolution. With the disk constant for each meter (shown on the face of the meter in terms of watthours per revolution), the total electrical energy consumption measured by the watthour meter could be calculated by multiplying the total number of counts (revolutions) by the disk constant. The meters had been checked for accuracy and recalibrated as required by New Brunswick Electric Power Commission technicians.

1.8.3.3 Integrating energy meters

Holman Electronic Controls' personnel were able to locate points on the printed circuit boards within the energy meters from which to obtain a sharp, square-wave voltage pulse suitable for use with the data acquisition system. Energy meter operation was checked after modification to ensure that performance and calibration had not been altered inadvertently. All energy meters were checked for accuracy by passing cold water through a water meter of known accuracy and then through the energy meter; at the same time, the high temperature sensor associated with the energy meter was immersed in boiling water. For the Rho-Sigma meter, which uses remote high and low temperature sensors, the low temperature sensor was immersed in an ice-water mixture. The two ISTA meters, which incorporate the low temperature sensor in their flow-measuring section, were supplied with cold water from the laboratory water system the temperature of which was measured using an accurate thermometer. All meters were tested for several hours at each of three flow rates and so, to confirm that temperatures did not vary significantly during each test, a strip-chart recorder and two thermocouples were used to provide continuous monitoring of the temperature difference between the hot and cold sources. The energy that should have been measured by the energy meter under test was calculated from the known mass of water passed through the meter (obtained from the water meter), the temperature difference between the hot and cold sensors, and the specific heat of water; this was compared to the difference between the final and initial readings displayed by the energy meter. The difference between the actual and indicated energy readings was expressed as a percentage, and used to correct readings taken both manually and by the data acquisition system. The Rho-Sigma meter and one ISTA meter were found to operate with negligible error, while the second ISTA meter was found to read high by 4.5%.

1.8.3.4 Water meters

The water meters were modified by Holman Electronic Controls in order to obtain a repetitive, de-bounced, switch operation whenever the meter was in operation. Modification did not affect meter operation, and the original mechanical read-out mechanism was left intact. The relationship between the number of switch closures and the volume of water passed through the meter was determined by observing the total number of counts read by the data acquisition system as water was collected and weighed in a large plastic container. The volume of water was calculated from the measured weight and the density of the water. The ratio of switch closures to litres of water yielded the calibration factor used in reducing data logged by the system.

1.9 Fire alarm system

Because the Heat Harvester was an unproven appliance the operating characteristics of which were unknown, and because it was considered prudent to provide as much warning as possible in the event that a fire should develop in the fuel storage or feeding systems or around the appliance, a linked or interconnected fire-alarm system was selected and installed. Experience with both ionization and photoelectric detectors installed near the wood chip stoker/boiler installation used prior to installation of the Heat Harvester had shown that the ionization detectors were the most sensitive, and so the decision was taken to install that type of detector. Because of the layout of the house, it was considered essential to provide a system that would sound an alarm both at the detector mounted near the appliance and its fuel supply and also in the bedroom area; since the Heat Harvester was expected to operate unattended during the day and also possibly over several days at a time, an outdoor alarm was needed in order to alert neighbors who could then respond as required. Battery operated alarms of the type sold at many retail outlets are not designed for interconnection, and so various commercial/industrial detector and alarm systems were considered. Of these, detectors offered by Edwards of Canada, Owen Sound, Ontario appeared to serve the purpose and to offer relatively simple installation without need for special control panels or annunciation systems.

The detectors are powered by 120 volts AC and are installed on a separate circuit breaker in the main house distribution panel; no other outlets or equipment is installed on this circuit. One detector (Model 360IT) is equipped with both an ionization and a thermal detector - the thermal detector operates at 57C (135F) - and is located on the ceiling of the boiler room. The second detector (Model 360IR) is located on the ceiling of an upstairs hallway outside the bedroom doors; it is of the ionization type and incorporates a SPDT (single pole double throw) relay. The relay operates whenever the detector's alarm is operating and is used to control a 120 volt, weatherproof alarm bell mounted outdoors under the peak of the roof at one end of the house. Each detector incorporates an interconnection terminal which, if wired to that on the other detector, causes the alarms in both detectors to sound when any one detector is tripped. The manufacturer's literature indicates that a total of twelve similar (360 series) detectors may be interconnected in a single installation. In addition, the circuitry provides for alarm triggering by closure of any type of switch connected between the neutral (white) power supply line and the interconnection line; therefore devices such as manually operated pull stations or thermally operated switches could also be connected to the alarm system and, if tripped, would trigger the alarms in both detectors and would cause the outdoor bell to ring.

2 SYSTEM COMMISSIONING

Initial attempts to operate the Heat Harvester were not successful. After the unit had been assembled, electrical power connections made, and a small quantity of fuel placed in the hopper, the system was energized. At this point, the Heat Harvester had not been coupled to the boiler, but was being test-fired to check its operation. A variety of problems were discovered.

2.1 Time-delay relay failure

When the Heat Harvester was connected to the 120 volt electrical supply, the forced draft fan started and ran continuously; this happened despite the manual control switch being set to the off position. It did not seem logical that the first thing to happen in the operating sequence for the burner was that the forced draft fan should operate, especially with the unit turned off. Attempts to trace the wiring in the control panel were frustrated because the wiring diagram provided with the unit did not correspond to the wiring in the panel. A series of tests performed on the burner while in telephone contact with the manufacturer led to identification of a plug-in time-delay relay as the probable cause of fan operation. The relay in question, designated as T2, is intended to cause the forced draft fan to run for an adjustable length of time following normal shut-down of the burner. Electrical tests on the relay revealed that its normally open contacts were in fact closed, and visual inspection after dismantling it showed that the contacts were welded closed; how, when or why the relay became damaged is not known. It was made operable by gently prying the contacts apart and then dressing them with a fine abrasive. With the repaired relay in place, the forced draft fan appeared to operate as intended. Two replacement relays were supplied by the burner manufacturer, one of which was substituted for the repaired unit on receipt.

2.2 High-limit thermocouple failure

Initial attempts to obtain ignition of the fuel and sustained burning were thwarted by an apparent failure of the fuel feed system drive motor; the motor had operated as expected during initial brief trials, but ceased to function as though due to some sort of failure in its electrical supply. The problem was traced to an open thermocouple used in conjunction with the temperature control that prevents excessive temperatures in the combustion chamber wall. The control, designated as TB2, is arranged to fail in a safe mode by shutting down the fuel feed system in the event of thermocouple failure. It is believed that the thermocouple failed because no allowance was made for thermal expansion in the thermocouple itself, or for differential expansion between the inner cylinder forming the combustion chamber wall against the outside of which the tip of the thermocouple rested, and the outer cylinder to which the thermocouple was rigidly mounted by a tight compression fitting. A new thermocouple was built, and a spring-loaded mounting arrangement was devised for it; this ensured intimate contact between the exposed thermocouple junction and the combustion chamber wall, and also permitted the thermocouple to slide axially to accommodate thermal expansion. A section of the steel framework at the front of the hopper was removed in order to make room for the spring mounting system, and also to permit routing of the thermocouple lead wire; the frame was judged to be very rigid and no problems resulted as a consequence of the modification involved. The replacement thermocouple and revised mounting system performed without problem once installed.

2.3 Stoker auger defects

Once the control problems discussed previously had been solved, further attempts were made to obtain combustion. On two or three attempts, the fuel ignited but the fire burned very weakly and the controls shut the system down. On the fourth attempt to start the unit, the fuel feed system jammed. Inspection of the system in anticipation of finding an over-sized fuel particle instead revealed that the transfer box between the two augers was filled with solidly compacted chips; these had to be pried loose with a screw-driver. When the transfer box was emptied, it was found that the lower, stoker auger was missing its helical flights over that portion of its length within the box; flights were in place on the section extending into the combustion chamber. The auger was removed and flights were fabricated and welded to it in order to complete it. With the rebuilt auger in place, it became possible to operate the Heat Harvester and to maintain a hot fire.

2.4 Speed control ground fault

An annoying and initially puzzling auger drive motor failure occurred during early attempts to operate the Heat Harvester. Motor failure was traced to a fuse located, somewhat inconveniently, inside the motor speed controller; the speed controller had to be dismantled by removing four screws and withdrawing its front panel and circuit board in order to reach the fuse. After several fuse failures and replacements, originally attributed to an electrical fault in the motor, burn marks were noticed near a mounting screw used to attach the plastic case of the speed controller to the steel control panel housing. Closer inspection revealed that a terminal on one of the components on the circuit board was located immediately opposite the mounting screw and was so orientated that it just made contact with the screw when the speed control was assembled. The problem was cured by applying several layers of electrical tape over the head of the offending screw as well as over those of the other mounting screws.

2.5 Fuse holder wiring

Two problems related to the main fuses used in the control panel were discovered during early test work. The first involved complete failure of the electrical supply within the control panel, despite the presence of 120 volts at the input terminals to the panel. The obvious source of the problem appeared to be the 15 amp time-delay cartridge fuse in the control panel, and yet the fuse itself had not blown. However it was noticed that parts of the plastic body of the fuse holder had become deformed and appeared to have softened or melted. When the fuse was reinserted in its holder, it was found that the upper clip of the holder did not grip the fuse's ferrule tightly. By pressing the fuse firmly into the holder, it was possible to reactivate the Heat Harvester, however, once pressure was released, the electrical supply was interrupted and the machine stopped working. The cause of heating was clearly due to the relatively poor, high resistance contact being made between the fuse and the holder. The holder was removed, the fuse retaining contact in it cleaned and bent to increase contact pressure between it and the fuse, and the holder re-installed, thus ending the power failure problem.

The second problem was detected quite quickly when working on the fuse holder. The holder is of swing-out design such that fuse removal requires pulling the top of the plastic fuse carrier outwards and, in so doing, disconnecting the top ferrule of the fuse from its electrical contact. The top contact is supposed to be wired to the incoming or line side of the electrical supply so that contact with the fuse in order to remove it from its holder poses to no electric shock hazard. Removal of a blown fuse in fact does pose no danger because the fuse is electrically open. However, when a replacement fuse was inserted in the open holder, an electric shock was received. Examination of the wiring showed that both fuse holders had been wired incorrectly so that when open, the entire fuse body was electrically alive. The solution required reversing the connections to the top and bottom of both fuse holders. The problem was considered potentially lethal and so was reported immediately to the manufacturer, who stated that another system had displayed the same problem and that he was aware of the trouble.

3 PRELIMINARY TESTS

3.1 Fuel characteristics

The wood chip fuel prepared for use in the Heat Harvester was made from seasoned hardwood; the trees had been harvested and cut to 2.5 m (8 ft) lengths and then piled outdoors for 9 to 12 months prior to being supplied for use in the Heat Harvester project. The wood was reduced to a nominal 13 mm square by 4 mm thick chip size (much smaller than conventional pulp chips) by a tractor-driven Arvin chipper. The chips were passed through a vibratory screen after they were discharged from the chipper; the screen removed almost all large pieces, although about 3 percent by weight of the screened material consisted of long, straw-like particles produced as a consequence of using inadequately sharpened blades in the chipper. The material that passed the screen was conveyed to a 3 m by 6 m (10 ft by 20 ft) drying bin where ambient air was blown upward through the 2.5 m deep bed of chips. The drying process reduced the moisture content from approximately 40% to less than 20% (wet basis).

Samples of the dried chips were passed through a set of standard sieves mounted in a sieve shaker, and the particle size distribution was obtained. The results are presented in Appendix V.

Bulk density measurements were made to further characterize the fuel; these involved measuring the weight of chips required to fill a 0.07 cu m (2.46 cu ft) box when the box was first filled by pouring the chips into it loosely, and then again when the box was filled to the maximum possible quantity of chips by vibrating it after each addition of chips. The resulting bulk densities are reported as the loose bulk density and the settled bulk density respectively.

Throughout the test program, chip samples of about 500 g (1 lb) were taken at random intervals, were weighed, and then were oven dried at 105C (220 F) to constant weight and then the wet-basis moisture content was determined by dividing the loss in weight (water evaporated) by the initial weight of the as-received sample. The resulting ratio, multiplied by 100, yields the percent moisture content. This figure was required to determine the gross energy input to the burner associated with the mass of dry fibre supplied per unit time from the known mass flow rate of as-supplied fuel.

3.2 Fuel feed rate

The Heat Harvester uses a high torque, variable speed gearmotor to drive the fuel feed augers. The speed is varied by adjusting a rotary control, the setting of which ranges over a scale marked from 0 to 10. Tests were conducted in order to determine the effect of various control settings on the actual fuel feed rate. A diversion chute cut and formed from 20 ga aluminum was fitted into the inspection/clean-out port in the transfer box between the two fuel feed augers; the chute was arranged to intercept all material falling from the hopper auger and to discharge it into a 20 l plastic container. Several tests were conducted at a convenient, low speed control setting (usually 4) during which the time to fill the container was measured using a stop-watch; the weight of fuel collected was then determined. During each individual test run, care was taken to ensure that the auger in the fuel hopper was fully supplied with fuel, and that no bridging or other problems occurred. The mass flow rate in terms of kg/h and lbs/hr was calculated using the average of the experimentally obtained results. The tests were then repeated at a higher control setting (usually 8). The results from the low and high speed tests were then plotted, and a straight line drawn between the two points and extrapolated over the range of possible control settings. That the relationship between speed setting and fuel feed rate was linear was confirmed by running additional tests at settings other than those used for the original measurements, and noting that the plotted results fell on, or very close to, the plotted line.

Many different fuels were burned as part of emissions test work performed by the New Brunswick Research and Productivity Council in conjunction with Adsett and Associates (1). Fuel feed rate tests were performed for each of these and revealed quite large differences between the various fuel types. The results are presented in Appendix VI.

3.3 Combustion efficiency measurements

Combustion efficiency was determined by measuring stack gas temperature, carbon dioxide content in the stack gas and, using previously determined values for the fuel's moisture content, referring to curves prepared by Roberts et al (2). Stack gas temperature was measured at a point 280 mm (11 in) downstream from the flue collar on the boiler. Stack gas carbon dioxide content was measured using a Bacharach Fyrite gas analyzer; the adequacy of the absorbent solution in the analyzer was tested routinely following the manufacturer's instructions. Gas samples were drawn through a small hole in the flue collar through which the sampling probe could be fully inserted into the gas stream. Cleanliness of combustion was estimated by measuring the smoke number using samples drawn through the same opening used for gas analysis.

For a given fuel feed rate (set using curves prepared as described in section 3.2), the primary (under-fire) air supply was adjusted to give the highest achievable carbon dioxide results together with a low smoke number. Secondary (over-fire) air was added to try to further reduce the smoke number, albeit at a reduction in carbon dioxide level. The damper mechanism on the Heat Harvester was such that inlet air adjustments could not be made with any degree of precision, nor could the settings established for a given fuel feed rate be recorded for use at a later time, and then re-set when needed. For this reason, and also in an attempt to measure air flow into the combustion chamber, a calibrated air-flow nozzle was installed in the inlet system to the forced draft fan. The pressure drop across the nozzle was measured using a sloping-tube manometer; the measured pressure drop, ambient barometric pressure, temperature and relative humidity were used to determine the mass flow rate of air through the nozzle. For practical purposes, barometric pressure, ambient temperature and relative humidity corrections were negligibly small, and so pressure drop readings were of use to set the primary and secondary air dampers. At the start of a test, both dampers were closed as completely as possible, and then the primary air damper adjusted as outlined earlier; once set, the pressure drop across the flow nozzle was recorded, and then the secondary air damper was adjusted. This resulted in increased flow through the fan and therefore an increase in pressure drop; the total pressure drop was recorded. With a record of the pressure drops related to primary air flow and total air flow, it was possible to re-establish damper settings at any time to obtain similar air flows.

Work conducted during the spring of 1985 (1) yielded damper settings judged to result in the best overall performance of the Heat Harvester with a fuel feed rate set to provide a gross energy input of approximately 53 kW (180,000 btu/h). Settings close to these were used for routine operation of the Heat Harvester; minor adjustments were made to accommodate differences in fuel characteristics and also in an attempt to improve reliability of automatic ignition.

4 OPERATIONAL PERFORMANCE

4.1 Test program 1984-85

Overall objectives of the test program were stated earlier in section 1. The original intent was to operate the Heat Harvester for all space heating in a house and, on alternate weeks, for DHW heating as well. It was planned to use the system over as much of the 1984-85 heating season as possible. Because of the many problems encountered with the Heat Harvester relative to its assembly, installation, commissioning and operation, the actual time over which it was used for any useful heating purposes was very brief. The machine was delivered in late September, 1984; the first attempt to test-fire it under purely manual control with the unit connected to the boiler, took place in early December and at that involved use of a make-shift ash receiving pan. Provision of an ash handling system to couple properly with the Heat Harvester involved long delays, with delivery of only a part of the required components taking a full month from placement of the order; other special components were not obtained until after attempts to deal with the original supplier were abandonned, and direct contact was established with the manufacturer. Then mounting brackets and a drive system had to be designed and built in order to assemble correctly with the available parts and the

Heat Harvester.

After further modification of the boiler to (1) permit a relatively tight seal between the boiler and the burner-to-boiler connecting duct, (2) achieve an appropriate boiler temperature control scheme for use with the Heat Harvester and (3) to install and control the first draft inducer, a second attempt was made to place the Heat Harvester in routine service. The machine ran from noon on February 3rd until 8 am on February 4th, when it was taken out of service because of unreliable operation and the consequent risk of frost damage to the plumbing systems in the house. Automatic transfer to a back-up heating system was not available because plumbing connections to the then existing oil-fired boiler had not been arranged for the purpose, and the planned electric boiler and its associated, revised piping system, had not been acquired. A further problem occurred during attempts to improve automatic ignition; as a result of opening the ash clean-out door in the boiler during burner operation, and therefore losing over-fire draft, some combustion gases moved back through the fuel feed system and caused the automatic fire-extinguisher to discharge. The extinguisher had to be sent to Halifax (the nearest service centre with parts and chemicals in stock for this type of extinguisher) for refilling, and then returned via courier service because, as a pressurised device, other carriers could not handle it. The cost to refill and ship the unit ($50) and the total time the burner was out of service due to lack of a fire protection system (two weeks) are both considered excessive.

Attempts were made to obtain reliable, fast ignition of the fuel through various adjustments and modifications to the Heat Harvester; these were made in consultation with the manufacturer, and included repositioning of the control thermocouple within the combustion chamber to locate it above the ignition element, and also bending the ignition element downwards in order to obtain positive contact between it and the incoming fuel sooner than had previously occurred. The former adjustment did not change ignition performance, and the latter resulted in destruction of the metallic jacket, and subsequent failure of the electric resistance heating wires in the ignition element. No further attempts were made to use the Heat Harvester for routine heating during the 1984-85 heating season because it was scheduled for inclusion in an emissions test program (1) and test personnel efforts had to be directed to acquiring and preparing the various fuels needed for that purpose. Emissions tests on the Heat Harvester were performed during the period from April 2nd to the 15th, 1985.

During the emissions tests, difficulty was often encountered in achieving automatic fuel ignition and therefore it was often necessary to start the fire by using a hand-held propane torch, the flame of which was directed into the combustion chamber through a small port ordinarily used for viewing the fire. Also, it was observed that severe fuel bridging and piping (rat-holing) took place in the fuel hopper, and so, in order to ensure uniform fuel feed to the fire during testing, the fuel in the hopper was stirred manually. Both problems were addressed during work done to determine the effect of fuel characteristics on the performance of the Heat Harvester reported in (3). Ignition performance was improved largely through trial-and-error testing, and seemed to be affected by the extent of control thermocouple insertion and also by forced-draft fan damper settings. In order to overcome the fuel-flow problems in the hopper, a pair of stirring shafts were installed in the base of the hopper, one on each side of the hopper auger. Each shaft carried four rugged paddles, and the shafts were positioned to provide about 25 mm (1 in) clearance between the tips of the paddles and the adjacent hopper surface and auger. The shafts were chain-driven from a sprocket mounted on a shaft extension fitted to one end of the hopper auger.

4.2 Test program 1985-86

As a result of testing performed during the summer of 1985, various control settings were established that seemed to yield reasonably reliable fuel ignition coupled with good efficiency and acceptable smoke numbers. These settings were used in an attempt to operate the Heat Harvester for routine heating over the 1985-86 heating season.

The Heat Harvester was started on October 24th and ran, with various shut-downs as detailed later in this section, until January 23rd when the auger drive motor failed. After replacement parts for the motor had been obtained (a lengthy delay because the manufacturer had no stock of the gear needed) and installed, the Heat Harvester was again put in service, and operated from April 16th until May 12th, at which time the unit was turned off because the heating season was over. In total, the unit operated - not without problems - for four months of the seven month (nominally mid-October to mid-May) heating season.

4.2.1 Observations - recorded data

Manual records taken during the months that the Heat Harvester was operated are in Appendix VIII. Because of the persistent ignition and other problems experienced with the Heat Harvester, very few long, trouble-free periods of operation occurred, and therefore it is difficult to draw useful conclusions relative to appliance efficiency. A major problem relates to determining the gross energy input to the appliance in that, due to appliance configuration, nature of its connection to the boiler, and ease of access for fuelling, the fuel consumption was measured indirectly. As described earlier in section 3.2, the fuel feed rate was related to auger drive motor speed control setting so that, knowing the total motor running time it is possible to calculate reasonably accurately the total mass of fuel consumed. However, because of the frequency of ignition failures and of the cyclic operation of the control system as it attempted and re-attempted to achieve ignition, unburned fuel was displaced along the combustion chamber and into the ash collection system and also into and through the burner-to-boiler duct. As a consequence, while the timer used to measure fuel auger run time did indeed permit calculation of the total quantity of fuel delivered to the combustion chamber, not all the fuel was burned or burned cleanly in a hot, controlled fire. The efficiencies that can be calculated reflect poor ignition and the resultant fuel-rich, smoky combustion, and are very low.

4.2.2 Results

For the reasons outlined in section 4.2.1, overall thermal efficiencies have been calculated for only two periods of time, October 24-29 and November 1-21. During both periods, the Heat Harvester was used to supply space heating only. During the one week-long period in December that both space heating and DHW production were involved, the Heat Harvester malfunctioned as noted in the daily performance record for that month in Appendix VIII; therefore calculations of overall thermal efficiency have not been made for that period.

October 1985 24th to 29th
Speed setting 5: small hardwood chips at 10% mc (wet basis)
From curves (Appendix VI) fuel mass flow rate is 23.75 lb/h
- at 8600 btu/lb dry fibre, this is equivalent to a gross energy input rate of 23.75(0.90)(8600) = 184,000 btu/h (or 54 kW)

Energy input is (1672.75-1656.75)(23.75)(0.90)(8600) = 2,941,200 btu
Energy output is (38408-38270)(3413) = 470,990 btu
Overall thermal efficiency is ((470,990)/(2,941,200))(100) = 16%

November 1985 1st to 21st
Speed setting 4.75: small hardwood chips at 10% mc (wet basis)
From curves (Appendix VI) fuel mass flow rate is 22.5 lb/h
- at 8600 btu/lb dry fibre, this is equivalent to a gross energy input rate of 22.5(0.90)(8600) = 174,200 btu/h (or 51 kW)

Energy input is (1749.3-1685.25)(22.5)(0.90)(8600) = 11,154,300 btu
Energy output is ((38938-38545)+(31344-31107))(3413) = 2,150,200 btu
Overall thermal efficiency is ((2,150,200)/(11,154,300)(100) = 19.3%

4.3 Observations - system operation

4.3.1 Ash removal

The Heat Harvester was not able to de-ash itself automatically. As noted in the daily performance records, the combustion chamber became plugged to the extent that some combustion gases moved back through the fuel feed system and fuel hopper and into the boiler room. The problem appeared to be due to the lack of any form of mechanism to induce ash flow into the ash removal port near the exit from the chamber; accumulations of ash, heated by successive fires, became sintered into a low density, cake-like mass that bridged over the ash removal port and eventually all but blocked the 250 mm (10 in) diameter combustion chamber gas outlet. Moderate ash accumulations had been removed on several occasions as other work was done on the burner, and these cleanings were not recorded because they were subordinate and coincidental to some other repair or maintenance operation. During attempts at routine system operation, records show that the operating time from a well-cleaned chamber to a plugged condition was 115 hours over a total of 19 days.

4.3.2 Burn-back

Following a hot fire and satisfaction of the demand for heat, the Heat Harvester went into a controlled shut-down cycle. This involved continued operation of the forced-draft fan for a pre-set period of time during which whatever amount of fuel remained in the combustion chamber was burned quickly and cleanly. The fire did not, however, burn out completely within the combustion chamber; instead, it burned back along the fuel lying on the bottom of the stoker auger conduit. Burn-back combustion involved open flame, and the conduit surface temperatures achieved were sufficiently high to burn the paint outside the conduit. Stack-induced over-fire draft remained high enough (2 to 5 Pa) to ensure that combustion gases travelled towards the boiler and to the chimney rather than reversing direction and exiting through the fuel hopper. The high surface temperatures - not measured, but known to be in excess of 100C - were a cause for concern both because of the potential for fire-spread into the fuel hopper, and because of the burn hazard posed to the operator during routine maintenance.

4.3.3 Ignition reliability and fire maintenance

With the dry, uniform fuel supplied to the burner, it was anticipated that fire starting should have been highly reliable. However, difficulty in achieving reliable, quick ignition of the fuel was experienced throughout all attempts to operate the Heat Harvester. During ignition, fuel supplied by the stoker auger had to accumulate to a height within the combustion chamber sufficient to reach and contact the hot ignition element. The thermocouple used to sense fire temperature is located about 25 mm below the ignition element. During ignition, the thermocouple temperature could be seen to rise (it is displayed on the front panel of the control system) until it reached the pre-set, field-adjustable trip-point on the control to which it is connected; then the ignition element is turned off, the fuel-feed system and the forced-draft fan are turned on, and the supply of combustion air blown upwards past the thermocouple through the fuel permits rapid establishment of an intense fire. However, frequently the onset of forced-draft and fuel feed resulted in the thermocouple tip temperature falling below the trip-point. Whether the cool, incoming fuel working its way up past the thermocouple tip served to quench the thermocouple, or whether the flow of combustion air cooled the thermocouple, or whether some combination of both possible cooling mechanisms was at work is not known. The observed system performance nevertheless involved repeated on and off cycling of the ignition, forced-draft, and fuel-feed systems. On the many occasions when cycling was detected by the operator it was noted that a brisk fire had actually been established, and it was possible to interrupt the cycling behaviour by physically moving the thermocouple further into the combustion chamber by 25 mm to 75 mm (1 in to 3 in); this put the thermocouple tip into a hot region of the fire, satisfied the control system, and permitted continuation of the burn until the demand for heat was satisfied. Unfortunately, the thermocouple position required for cycle-free operation after the fire had been started was not appropriate for sensing initial ignition. If the thermocouple was left in its revised position, then during a subsequent attempt at ignition from cold, the thermocouple would not sense heat from the incipient fire and the forced-draft fan would not be turned on; under such conditions, the failure of the thermocouple-controlled relay to operate within an acceptable period of time (field-adjustable up to one hour, but typically 30 minutes) resulted in the control system shutting down the Heat Harvester and transferring to the back-up heating system. On many occasions, the thermocouple failed to sense fuel temperatures during ignition despite visible flame having been established and also despite the thermocouple tip being located directly below the igniter; this resulted in eventual transfer to the back-up heating system. It is surmised that accumulations of ash had built up around the thermocouple and were insulating it from the heat of the fire; at times, ignition performance could be improved by dislodging material around the thermocouple using a 6 mm rod inserted through the view-port at the rear of the combustion chamber.

A closely related problem was noticed on many occasions when a hot fire had been started and thermocouple tip temperatures had risen to normal maximum values; the thermocouple temperature would start to drop and would eventually trigger an ignition cycle. The problem seemed to be related to a tendency for the fire to at times gradually move down the length of the combustion chamber so that the hottest region became displaced away from the thermocouple; then the thermocouple could only sense temperatures within the incoming fuel. This would tend to suggest that the fuel feed rate was excessive, yet this occurred with dry fuel supplied at an energy input rate of 54 kW (184,000 btu/h) well below the manufacturer's rated output of 175 kW (600,000 btu/h) with such fuel, and with a clean fire which indicated that adequate air was being supplied.

4.3.4 Noise

The Heat Harvester is intended for institutional and commercial installations where noise generated by the appliance is of little concern or can be accommodated through building layout and design. For a residential installation, noise levels developed by the device are excessive. The sole source of irritating, though not intolerable, noise from the Heat Harvester is the forced draft fan. It may be that selection of a different fan, perhaps operating at a lower rotational speed than the 3500 rpm unit supplied, could reduce sound levels appreciably.

4.3.5 Stoker auger failure

During operation of the Heat Harvester, it was possible to observe the interior of the combustion chamber by looking through a port installed in the boiler opposite the duct connection between the boiler and the burner. It was noticed that those flights of the stoker auger closest to the fire operated at a bright orange temperature. When the Heat Harvester was delivered, the flights exhibited quite deep pitting due to rust - the auger clearly was not in new condition when installed in the Heat Harvester. A test with a magnet confirmed that the flights were not of stainless steel. The high temperatures to which the flights were exposed led to their gradual deterioration and eventual failure in mid-January, 1986, with consequences discussed in section 4.3.6. The total burner operating time from its first use in early February, 1985 until the auger was removed for rebuilding was approximately 770 hours. Had the burner been operated at full output on a continuous basis, this would have been equivalent to a running time of about 32 days.

4.3.6 Drive motor failure

The drive motor used to operate the hopper and stoker augers and also, after the system had been modified, the two fuel stirring shafts in the hopper, is a 50 w (1/15 hp), 90 volt DC, variable speed gear-motor (Dayton model 4Z530). It is rated at 56 N.m (500 in.lbs) at 6.5 rpm. On two occasions the motor failed due to breakage of teeth in the cast iron final output gear of the speed-reducer supplied as an integral part of the motor. According to the motor's manufacturer,

> "Use of SCR controls without current limiting capability can result in gear damage because the unlimited stall torques of a PM (permanent magnet) motor exceed full load torque ratings of the gear box."

Elsewhere in the same bulletin, the motor manufacturer states,

> "Always use Dayton filtered controls 6X165 or 5X412 or unfiltered control 4Z527 with all

> models of PM gearmotors listed in this manual."

The correct bulletin for the 4Z527 speed control fitted to the Heat Harvester was not provided with the machine; however, the bulletin accompanying a model 5X412 speed control states,

> "CAUTION: This controller does not have current/torque limit feature. A DC motor can develop starting torque of up to 600% of its full load rating. The line fuse will protect against continuous overload. Fuse properly, see Fuse Selection Table."

It would seem that there is need for some co-ordination within the motor manufacturer's organization in that conflicting information is provided to users of the motors and controllers. In any event, damaging torques were being developed, and gear failures resulted. It may be that some alternative speed controller should be installed on the Heat Harvester in order to protect the motor.

The high loads imposed on the drive motor and drive chain system were originally thought to be due to the addition of the fuel stirring mechanism in the hopper. However, the problem is now considered to be due to the progressive deterioration of the auger flights on the stoker auger. As noted on December 10th, one of the drive chains was found to be skipping teeth on one or another of the sprockets around which it passed. The problem was intermittent and could not be traced on its initial occurrence by watching the drive in operation. When the burner was dismantled after a chamber plugging incident on January 6th, the extent to which the stoker auger flights had deteriorated was readily noticeable. At the same time it was found that the chain used to drive the stoker auger was under extremely high tension, an unusual situation because the torque required to turn that auger is normally very low. After the combustion chamber had been cleaned, the auger once again became easy to turn. It was decided to rebuild the stoker auger using stainless steel flights in place of the mild steel material, and flights - rolled to order so as to fit the auger - were ordered on January 10th. While awaiting manufacture and delivery of the new flights, the Heat Harvester was again operated, but either due to previous overloading or to loads developed during this period, the motor gear failed. When the stoker auger was removed, it was found that the final turn or two of mild steel flighting had oxidized to such an extent that the flights had lost strength and had folded almost flat against the auger shaft. Previous experience has shown that it is essential to run an auger used to convey wood chips through the entire length of the conduit; if the auger is slightly shorter than the conduit, then eventually the chips will plug in the conduit and stall the auger. The loss of flights due to high temperature oxidation would lead to a condition equivalent to operating an auger of inadequate length and would have led to the overload which caused the motor failure.

4.3.7 Mounting plate deformation

Subsequent to the gear failure that took place in January, 1986, it was noticed that the 3 mm (1/8 in) plate to which both the gear motor and the pillow-block bearings used to carry a chain-driven jack-shaft were bolted, had become distorted. The high loads encountered are believed due to problems discussed in the previous sections. Before reassembling the Heat Harvester, the distorted mounting plate was removed and a heavier plate of 6 mm (1/4 in) steel was fitted in its place.

5 STORAGE-TO-HOPPER FUEL HANDLING SYSTEM

5.1 Introduction

A secondary objective of the work performed in this contract related to the design, installation and demonstration of a mechanical fuel-handling system to move wood chips from a bulk-storage bin into the fuel hopper of the burner. Interest in such a system derives from a desire to fully automate fuel handling to:

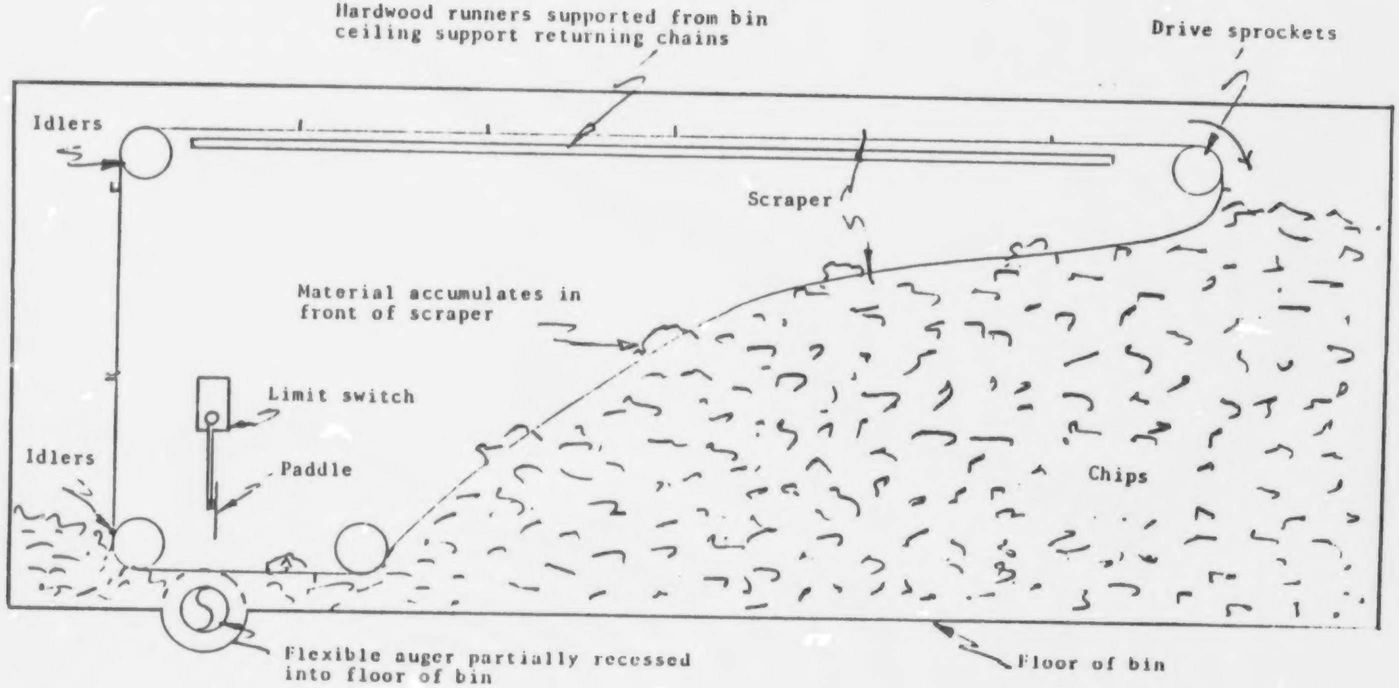
- improve convenience,
- make particulate wood-fuelled systems available to individuals who, for some physical reason, may be unable to cope with the shovelling and lifting,
- reduce the dust associated with some particulate fuels,
- reduce or eliminate contact with fungal spores that may be present in some fuels and which can cause an allergic reaction or infection in some individuals,
- reduce the delivered cost of fuel by enabling use of bulk (dump truck) rather than packaged (bagged, palletized) forms of delivery.

Constraints imposed on the design related to (1) flexibility, because whatever system was devised should be capable of installation with a wide variety of bin - house - burner configurations, (2) cost, because for residential installations the installed cost should be as low as possible, (3) versatility, because the system should be able to handle a variety of different particulate fuels, (4) dust containment, for reasons outlined earlier, and (5) the need to fit the existing bulk storage bin and couple with the burner.

5.2 Storage bin scraper system

The existing bulk storage bin is of wood-frame construction and stands on grade beside the house at the same level as the furnace room floor. Access to the bin from the house is through a 760 mm by 183 mm (30 in by 72 in) solid door. The bin has a width of 1.5 m (5 ft), a length of 6.9 m (22.5 ft) and a nominal height of 1.5 m (5 ft); details of its construction are given in (4).

In order to provide a feeder mechanism to bring chips from the bin to a single location from which they could be conveyed to the burner, initial consideration was given to use of a set of four 305 mm (12 in) augers located parallel to one another on the floor of the bin. Because of the relatively small quantity of material to be moved, such augers could be turned very slowly and calculations indicated that a small electric motor of about 370 w (1/2 hp) would probably suffice. However, calculations indicated that for the chips involved, the torque required to turn each auger would be very high, in the order of 2170 N.m (1600 ft.lbs); this was confirmed by measuring the torque required to turn a similar auger located under a 1.5 m depth of chips. The high


Hardwood runners supported from bin ceiling support returning chains
Drive sprockets
Idlers
Scraper
Material accumulates in front of scraper
Limit switch
Paddle
Idlers
Chips
Flexible auger partially recessed into floor of bin
Floor of bin

Storage-to-hopper fuel handling system.
General arrangement.
Fig. 5.2

torque values coupled with space limitations on the maximum chain sprocket diameter that could be used forced selection of very heavy chain and expensive sprockets. Also, the axial reaction forces due to auger action together with the tensile forces developed in the drive chain when operating would require a substantial steel frame to be built inside the bin because the wood frame of the structure could not be expected to carry the loads that would be developed. The cost and complexity of an auger type of bin feeder mechanism was considered excessive, and therefore an alternative feeding system was sought.

Live-bottom scraper chain systems of the sort used in agricultural equipment such as forage wagons and manure spreaders have been used by others to feed chips from bins. However the forces to operate such systems are high, and chain breakage can pose a difficult problem because such failure usually occurs under the load of chips in a fully loaded bin and therefore requires removal of the chips before repairs can be made. A suggestion made by a colleague, Dr. R. A. Douglas, to the effect that a system to scrape material off the top of the pile as opposed to one that dragged material from under the bottom of the pile should involve much lower forces, led to the system that was designed and built.

As built, the bin feeder consists of two continuous loops of detachable link conveyor chain between which are attached 1.2 m (4 ft) long scrapers of 25 mm (1 in) steel angle. Each loop runs just under the ceiling of the bin where it is supported on a hardwood runner. The chains pass over 6-tooth steel drive sprockets carried on a 25 mm (1 in) shaft that runs on bearings attached to the walls of the bin near the ceiling at the rear end of the bin. The chains have a large amount of slack in them so that they move down onto the surface of the chips. The loops are then pulled forward over the top of the chip pile and are drawn downwards to two pairs of idler sprockets mounted close to the floor at the front, or discharge, end of the bin; the first pair of sprockets forces the chain and scrapers downwards to ensure clear passage of each scraper under the operating paddles of the limit switches used to control the scraper-chain drive motor. From the second pair of floor-mounted idler sprockets, the chains are pulled upwards vertically and over another pair of idler sprockets mounted on the ceiling, from which they return to the ceiling-mounted hardwood runners. The drive shaft is chain-driven by a variable speed DC gearmotor identical to that used on the Heat Harvester. The 6.5 rpm (maximum) motor shaft carries an ASA 40, 60-tooth sprocket and this drives a 10-tooth sprocket on the conveyor chain drive shaft; this gives a speed increase of 6:1 and, at full motor speed, permits the conveyor chain drive shaft to turn at any speed between 0 and 39 rpm. The resultant scraper velocity ranges from 0 to 0.15 m/s (0.5 ft/s). The force required to stall the scraper-chain system is estimated to be about 70 lbs.

5.3 Transfer auger system

The scraper chain system delivers chips to a channel set into the floor of the bulk storage bin and running from one side of the bin to the other. In order to collect chips from the channel and convey them out of the bin and up to the top of the Heat Harvester fuel hopper, a flexible auger system was chosen. Augers consisting of a long helix of adequately strong steel which run in a relatively thick-walled PVCT plastic conduit are used in agricultural installations to convey, for example, various types of animal feed. Because the steel helix is not welded to a rigid, central shaft, such augers are able to move dry solid materials around large-radius corners as well as up or down inclines. One manufacturer of flexible agricultural augers is Chore-Time Equipment, Inc., represented in eastern Canada by Hurst Equipment Limited. Because experience with design of screw conveyors to carry wood chips has led to the conclusion that large diametral clearances are required between an auger and the conduit within which it runs, a modified version of one of the auger systems offered by Chore-Time was selected. Personnel at Hurst Equipment in Amherst, NS, were very helpful in making a non-standard selection of parts to permit assembly of a Chore-Time 60 mm (2-3/8 in) OD Model 75 auger in a 170 mm (4-5/8 in) ID, Model 125 conduit. A Chore-Time power unit consisting of a 250w (1/3 hp), 240 volt, 1725 rpm electric motor face-mounted to a speed reducer turned the auger at 348 rpm. The anchor bearing assembly required at the remote end of the auger had to be chosen to suit the 60 mm auger, and therefore required a special mounting adapter in order to fit it to the larger-sized conduit.

Overall, the installation involves a 1.5 m (4 ft 10 in) horizontal section placed in the channel in the bin floor, connected to two 45 degree elbows having a nominal centre-line length of 1.3 m (4 ft 3 in) each which together provide a 90 degree bend so as to result in the auger rising at an incline of about 55 degrees to the horizontal. A 150 mm (6 in) straight section connects the elbows to the power unit. The sections were joined together by first slitting the belled ends of each section, and then using a gear clamp to obtain a tight connection; in a conventional agricultural installation, the sections of conduit would be permanently connected using an appropriate adhesive. The connection method used in this installation permits rapid dismantling should this become necessary.

The initial, horizontal section of conduit was modified to permit entry of chips by removing three rectangular sections from the top of the conduit, each about 250 mm by 100 mm (10 in by 4 in) and spaced 75 mm (3 in) apart, to expose the auger within.

Preliminary tests of the system showed that if over-supplied with chips, the auger would jam. In order to prevent such jamming, a 1.2 m (4 ft) long section of industrial rubber hose was installed in the horizontal in-feed section. The hose was sized to fit closely inside the auger helix and displaces chips that might otherwise over-load the auger.

5.4 Controls

The scraper chain system in the bulk storage bin, and the flexible auger system between the bulk bin and the fuel hopper, are fitted with their own controls and can operate independently of one another. However, the control system on the scraper chain system will shut the chain-drive motor down if the scrapers supply material to the flexible auger system faster than it can be accepted. In practice, the scraper chain system operates until it has established a modest quantity of chips at the infeed openings to the flexible auger system; this accumulation of chips is detected by any one of three paddle-operated limit switches which are wired to interrupt the electrical supply to the chain drive motor and so shut it down. The flexible auger system in turn is controlled by two pressure-sensitive, diaphragm-operated, level controls fitted to the fuel hopper. When the level controls indicate low fuel level in the hopper, the flexible auger starts and continues to run until the upper level control is satisfied.

Operation of the flexible auger removes the small quantity of chips built up at its inlet by the scraper chain system; this permits the spring-loaded limit switches to reset, and therefore the scraper system starts and continues to run for as long as the flexible auger is in operation.

5.4.1 Scraper chain controls

The variable speed scraper chain motor is supplied with a DC voltage from the manually adjustable speed controller to which it is connected. The 120 volt AC supply for the speed controller is provided through three Siemens 3SE3120-1V rod-actuated limit switches wired in series. The switches were attached to a rigid steel frame so as to position one switch over the leading edge of each of the three slots cut into the horizontal section of plastic conduit in the floor of the bin; the switches were located so as to position their actuating shafts about 270 mm (10.5 in) above the bin floor. The aluminum rods supplied with the switches and ordinarily attached to their actuating shafts were replaced by 200 mm (8 in) long pieces of 6 mm (1/4 in) threaded steel rod to each of which was attached a 75 mm high by 185 mm wide (3 in by 7.25 in) 16 gauge galvanized steel plate; the rods were adjusted so that the bottom of each plate was about 125 mm (5 in) above the bin floor in order to allow room for the loaded chip scrapers to pass beneath them without operating the switches. Provided that the flexible auger system is in operation, the chips carried by each scraper fall through the slots and into the auger, which removes them. If the auger is not running for any reason, chips accumulate over the auger in the slots so that, by the time either the second or third loaded scraper tries to pass under the paddles, at least one paddle catches on the chips and is deflected sufficiently to cause the limit switch to open. As soon as any one of the limit switches opens, the electrical supply to the speed controller is interrupted and the drive motor stops. The system remains inactive until the flexible auger is started, the accumulation of chips at the paddles removed, and the limit switch or switches automatically reset, thus restoring electrical supply to the speed controller.

5.4.2 Flexible auger controls

The flexible auger is controlled by two diaphragm-operated, pressure sensitive, level control switches mounted on the fuel hopper wall, and also by a 24-hour time switch, all of which are used with a DPDT (double pole, double throw) relay which switches the 240 volt AC supply to the flexible auger drive motor. One level control is located near the top of the hopper at a point where it is able to sense the accumulation of chips as they pile up when falling from the flexible auger system when the hopper is full. The second level control is located near the bottom of the hopper close to, but offset to one side of, the bin auger exit opening; this control senses when the bin is nearly empty but is sufficiently far from the auger exit that is not affected by accumulations of compacted chips that form at times due to the presence of over-sized chips in some batches of fuel. The level controls are wired so that with the bin full, the switch contacts in both level switches are open. As fuel is consumed, the upper control senses the drop in level and its contacts close, thus completing part of the circuit to the operating coil of a relay. When the hopper is close to empty, the second level control operates and closes its switch contacts thus completing the relay operating circuit and closing the relay. The two sets of contacts in the DPDT relay that close complete the 240 volt circuit to the auger drive motor; one pair of contacts is also wired in parallel with the lower level control and so acts to latch the relay closed (ie, maintain relay operation) despite subsequent detection by the lower level control of the rising level of chips as the auger runs. When the level of chips is high enough to operate the upper level control, the switch in that control opens, and because it is wired in series with the relay control coil, the relay loses power and opens, thus stopping the auger. The time switch has been installed both as a precautionary measure and for convenience; experience with the chip-burning system is that hopper filling is required once a day or less. Because the scraper chain - flexible auger system is relatively unproven, it was considered prudent to force its operation once every 24 hours during the early evening when the house occupants are most likely to be present and to have time to attend to the equipment should trouble develop. Also, because the flexible auger is quite noisy when it runs, the early evening is the least disruptive time of day for it to run. The time switch is wired so that its switch contacts are in parallel with those of the lower level control; when it operates, provided that the upper level control indicates that the hopper is less than full, the auger motor runs and the hopper is topped up.

5.5 Performance

Experience to date with the automatic, mechanical fuel handling system has been good. The scraper chain and limit switch control system works as intended, and the inverted, 25 mm (1 in) steel angle scrapers ride over the top of the chip pile. The scrapers tend to collect chips from the rear of the pile and to then carry their load of chips over the pile surface and dump it into the auger in-feed slots; there is no operational problem as a result of this, although it has to be observed that unnecessary work is done in dragging chips from one end of the pile to the other. A setting of the scraper chain speed control at 40% of maximum seems to provide a good match between the capacities of the two conveying systems. The limit switch paddles required adjustment upwards to the positions described in section 5.4.1; they had originally been set to provide 75 mm (3 in) clearance from bin floor to bottom of the paddles, but this resulted in premature operation of the limit switches.

The flexible auger also performs as planned. Early experimentation with the auger showed that, if oversupplied with chips, the auger would jam and stall the drive motor. In an attempt to overcome this problem, a flexible rubber hose core was inserted through the centre of the entire length of the auger; this did not seem to resolve the jamming tendency, and so most of the hose was removed. As discussed in section 5.4.1, a 1.2 m (4 ft) length of hose was left in place at the in-feed to the auger, and this together with an appropriate scraper chain drive speed, appears to prevent auger jamming. No problems have been experienced with starting the auger while it was full of chips despite concerns that this might have been a source of trouble. The lower level sensor failed to operate even when the hopper was completely full, and so required adjustment; fortunately, the design of the device is such that the mechanism can be removed from the hopper without first removing the fuel, so alteration of its sensitivity was achieved quite easily.

In summary, the system works dependably, though because of the difficulties experienced with the Heat Harvester, it has not received much use. In order to gain operating time and experience with it, the fuel handling system has been fitted to the Skogma stoker that was used for heating prior to work on the Heat Harvester.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 General

The Heat Harvester incorporates several useful concepts and if developed further, it could become an efficient, reliable appliance for the production of heat from particulate wood and wood-like fuels. Unfortunately, experience with the burner over a period of two heating seasons was not good and revealed many problems which have been detailed elsewhere in this report; of these, the major concerns were 1) poor feeding of fuel from the hopper, 2) failure to allow for thermal expansion in the design and construction of the combustion chamber, 3) unreliable ash removal from the combustion chamber, and 4) unreliable detection and control of fire conditions during ignition and combustion of fuel. The problems encountered should have been identified by the manufacturer during thorough product testing prior to preparation of advertising literature and offering the appliance for sale. Assembly problems should not occur, and would have been avoided had the manufacturer assembled and test-fired the unit prior to shipping.

6.2 Test program

It was not possible to conduct the planned test program because of frequent system failures. The combustion system failed to operate for longer than five days at a time without operator intervention. Overall thermal efficiency values are low partly because of ignition-related, fuel-rich, combustion, partly because they can only be calculated for time periods when the load on the heating system was low, partly because of high amounts of excess air supplied through the fuel feed system, and partly because of unrepairable thermally-induced distortion of the combustion chamber which made control of under-fire and over-fire air impossible.

6.3 Heat Harvester design

Based on observations made of the Heat Harvester's performance, a number of suggestions can be made that should be taken into consideration by the manufacturer or any other individual seeking to develop this appliance, or seeking to undertake design and construction of a similar burner. The comments have, for the most part, been discussed earlier in this report or in (3), and some reflect an ad hoc attempt to remedy problems with the burner as it exists; redesign of the appliance may obviate many of the specific suggestions that follow.

6.3.1 Thermocouple mounting

Redesign the mounting arrangement used to support the thermocouple connected to control the maximum temperature of the combustion chamber wall. A spring-loaded arrangement as described in section 2.1 is preferable to the rigid mounting scheme used by the manufacturer because it is able to accommodate thermal expansion while maintaining firm contact between the thermocouple tip and the surface of the combustion chamber wall.

6.3.2 Ignition element

The time required from the initial call for heat until ignition is achieved (in excess of 10 minutes) could be decreased, and the reliability of ignition increased, by redesigning the ignition element so that a suitably curved, solid surface type of heater is used, and locating the heater flush with the bottom of the combustion chamber near the discharge end of the stoker auger. Fuel entering the combustion chamber would be heated above its ignition temperature immediately upon delivery to the chamber rather than having to accumulate in a pile to the height needed to contact the igniter in its present location.

Thought should be given to the method of making electrical connections to the igniter, regardless of its location. The exposed uninsulated terminals on the lower rear surface of the combustion chamber pose a shock hazard with the present design. It is suggested that a sheet metal terminal box be designed and supplied with the ignition element; wiring could be run to the box, and connections made within it.

6.3.3 Control circuit modification

When the manual selector switch on the control panel was turned from the OFF to the TB (tunnel burner, ie automatic operation) position, about 30% of the time the forced-draft fan would start to operate. The problem is described in (3), and was traced to momentary operation of relay R2. The brief contact closure resulting from this was sufficient to cause the fan control timer (T2) to run for whatever length of time had been selected for burn-out of the fuel during normal shut-down. That the fan should start some of the time during the ignition sequence was counter-productive because the resulting air flow tended to blow incoming chips away from the ignition element and also tended to cool both the chips and the control thermocouple. To cure the problem, a solid-state time delay module was installed in the circuit used to trigger operation of the timer, thus requiring an intended contact closure of duration greater than one second by relay R2 in order to start T2 and make the combustion air fan run.

A second problem also related to undesirable operation of T2, and therefore of the combustion air fan, was observed during the frequent re-ignition cycling that occurred with the Heat Harvester. Insofar as the control circuit was concerned, ignition failure during a burn appeared identical to normal shut-down and so resulted in continued operation of T2 (for the time period set on it) and so also of the fan. As outlined earlier in this section, operation of the fan during an attempt to kindle or re-kindle a fire was inappropriate. In order to block unwanted operation of the forced-draft fan, a relay was added to the circuit and connected so that it operated whenever the ignition element was energized; the switch contacts on the relay were wired in series with the power supply to the forced-draft fan, and so ensured that power to the fan was interrupted whenever the ignition element was in use.

It is suggested that a time delay device and an inter-lock relay be added to the control circuit of the Heat Harvester for the reasons and in the manner outlined above.

6.3.4 Optical fire sensing

It is suggested that consideration be given to abandoning the unreliable and expensive thermocouple-based fire sensing control presently fitted to the Heat Harvester. A photo-electric control similar to the flame sensor of the type used with residential oil burners but with a longer delay time (minutes rather than seconds) could be used to detect ignition, and if properly located, would detect fire regardless of flow patterns of incoming air and fuel or of changes in the location of the fire within the combustion chamber.

6.3.5 Burn-back control

As outlined in section 4.3.2, following a normal shut-down, the fire routinely burned back along the stoker auger and into the bottom of the transfer box between the hopper feed and the stoker augers. A self-actuating, temperature-operated, dry-chemical fire extinguisher mounted to discharge into the transfer box is intended to deal with fire in this part of the appliance should temperatures become excessive.

6.3.5.1 Fuel interruption system

It is suggested that some sort of scheme be devised to mechanically purge all fuel particles from the stoker auger as part of the normal shut-down procedure; this would eliminate burn-back in that there would be no fuel available along which fire could burn and reach the transfer box. One way to achieve such purging would involve relocating the stoker auger so that its flights rested on the bottom of its conduit; as presently arranged, the drive end of the auger is elevated 6 mm or so above the floor of the conduit, and so is unable to move all the chips in it through to the combustion chamber. Secondly, a steel flap located in the transfer box and hinged so that it could hang vertically downward during appliance operation, could be raised to a horizontal position by a spring-returned, two-position damper motor. In the raised position, the flap would intercept fuel particles falling from the hopper auger during a time-limited period over which the auger drive would continue to operate in order to empty the stoker auger. On a call for heat, the damper motor would be energized to lower the flap, and the fuel on the flap would be dumped into the stoker auger. Such a system would require purchase and installation of a suitable damper motor and also of an adjustable timer to provide continued operation of the auger drive for the required length of time to empty the stoker auger.

6.3.5.2 Fire extinguishing system - interlock

As supplied, the fire extinguisher could not be mounted on the Heat Harvester. The manufacturer should revise the mounting arrangement and, in doing so, should provide a more substantial fitting to seal the neck of the extinguisher to the opening on the transfer box than the Velcro-fastened nylon strap and whittled, softwood adapter shipped with the burner.

Because of the time delay and expense involved in refilling the fire extinguisher, it is suggested that an alternate fire suppression system be considered. The system that was fitted to the Heat Harvester to replace the original extinguisher used a water-filled 10 l (2 gallon) plastic reservoir mounted outside the fuel hopper and connected by flexible plastic tubing to a 74C (165F) automatic sprinkler head. The temperature setting for the sprinkler was the same as that on the extinguisher that it replaced. An air-tight, metallic mounting scheme was arranged for the sprinkler that permitted it to fit within the pipe coupling provided on the Heat Harvester for the fire extinguisher. The water deluge system thus arranged worked effectively when tested, and was reset in a few minutes by installing a replacement sprinkler head ($7) and refilling the reservoir with water.

Operation of either fire extinguishing system does not guarantee that the Heat Harvester will remain shut down afterwards. The automatic ignition system will respond to a call for heat, and will attempt to restart the fire and so to re-establish the conditions that led to extinguisher operation in the first instance. The gases produced by operation of the dry chemical extinguisher may be purged by action of chimney draft or an induced-draft fan and therefore fresh, dry fuel entering the combustion chamber could be kindled; very wet chips resulting from operation of the water deluge system are less likely to be ignited within the time allowed by timer T3, and therefore the Heat Harvester may well shut down and automatically transfer to the auxiliary heating system after failing to start the fire. It is suggested that, in order to ensure complete burner shut-down and also operator attention after a severe burn-back episode, a standard fire protection safety control (firestat) be installed in the transfer box; such a control would be connected to the auger motor circuit so as to inhibit the fuel feed system until after the control had been reset manually. Depending upon how it is wired, the control could also be used to trigger a fire alarm system such as that described in section 1.9.

6.3.6 Fuel feed system

It is suggested that the fuel hopper be redesigned to incorporate the principles presented by Bundalli (5). Such redesign, which would probably include changes in bin geometry, increased clearance for the bin feed auger especially at the outlet from the bin, and use of UHMP bin lining, may permit elimination of the fuel stirring shafts added to the Heat Harvester, and dealt with in section 4.1.

6.3.7 Hopper clean-out hatch

Access to the bottom of the fuel hopper in order to remove over-sized particles from the feed auger is very limited. One alternative is to remove the transparent plastic cover from the inspection window on the rear face of the hopper and to reach through the narrow opening thus created; the other is to climb into the hopper. Either option requires a considerable degree of flexibility, and the latter also some agility. In order to provide convenient, safe access to the hopper for any type of maintenance operation, it is suggested that a gasketted, hinged, access door fitted with a suitable latch be provided. Such a door was installed on the Heat Harvester, and was cut into the side of the hopper opposite that on which the control panel was mounted.

6.3.8 Combustion chamber

6.3.8.1 Buckling and cracking

The combustion chamber became badly distorted during the tests conducted over the summer period in 1985, with bulges forming in the side walls such that the original 255 mm (10 in) inside diameter became reduced to 180 mm (7 in) at places. Also, a 2mm

(1/16 in) wide circumferential crack developed around the combustion chamber, running from one side of the ash discharge port to the other, while a second horizontal crack about 100 mm (4 in) long developed at a welded seam along one side. The immediate effect of both the buckling and cracking is to cause loss of control of the fire, because the two heat-induced defects permit the under-fire and over-fire air supplies to mix before reaching the fire, and also allow combustion air to bypass the fire by exiting through the cracks rather than through the burning fuel. Details of the problem and possible solutions are presented in (3). The overall conclusion is that little or no attention was paid to thermal expansion and ways to control or to accommodate it in the design and fabrication of the combustion chamber.

6.3.8.2 Oxidation

Each of the three times that the combustion chamber was dismantled in order to repair buckling and cracking damage, flakes of oxidized metallic material that appeared to be from the combustion chamber were removed from the combustion-air inlet port. The exact origin of the material - whether from the outer surface of the combustion chamber wall, or from the inner surface of the stainless steel cylinder within which the combustion chamber is fitted - can only be determined by cutting the assembly apart, and in so doing, destroying it. Because such an examination was not undertaken, it is not possible to state with certainty where the metal damage had occurred. The conclusion can be drawn, however, that despite operation of the temperature limiting thermostat and control (TB2), which had been set to 870C (1600F), temperatures must have exceeded the 1040C (1900F) maximum recommended service temperature of the AISI 309 stainless steel used in the combustion chamber.

6.3.8.3 Combustion chamber mounts

The hot, outlet end of the combustion chamber is supported by two threaded studs which screw into a mild steel angle welded to the stainless steel face plate of the combustion chamber assembly. As discussed in detail in (3), it was noticed that whenever the combustion chamber was hot, the studs developed a pronounced backwards tilt (towards the hopper); this happened despite precautions having been taken to ensure a graphite-lubricated sliding support between the nuts and flat-washers installed on the studs to support them from the structural frame members provided for the purpose. The reason for the rotation of the studs was found to be an inadequate weld between the angle and the stainless steel plate; the weld had only barely penetrated the stainless steel, and therefore acted as a hinge and allowed the angle to rotate whenever the stainless steel chamber became hot relative to the cool outer steel cladding around the chamber assembly.

Attention to quality control and inspection of assembly details is required.

6.3.8.4 Heat transfer shroud - oxidation

A perforated steel shroud or hood is located around the stoker auger where it runs inside the combustion chamber; it is fastened to the rear (cool) end plate of the combustion chamber and projects into the combustion chamber about 150 mm (6 in). It is believed that the shroud is intended to absorb heat and to conduct it back in order to preheat fuel as it flows along the stoker auger. When delivered, the shroud had a light coating of rust on it; when tested with a magnet, it behaved like a mild steel. When the combustion chamber was undergoing repairs for other damage, the shroud was found to have deteriorated. It had become somewhat distorted from its original circular shape, and the free edge had been considerably erroded through oxidation, especially at the top. In view of the selection of a temperature-resistant stainless steel for other parts of the combustion chamber, it is surprising that mild steel should have been used for this component given the high temperatures to which it is exposed; the possibility exists that the material was chosen for its heat transfer characteristics rather than its longevity.

6.3.9 Stoker auger

6.3.9.1 Oxidation

Apart from having been supplied with some of its flights missing, the stoker auger was fabricated entirely from mild steel (section 4.3.5), and that portion of its flights nearest the fire were observed to operate at a bright orange temperature. The auger flights were noted to be visibly oxidized during system cleaning and inspection in early January, 1986 and failed completely later the same month. They were replaced with custom-ordered stainless steel flights which should be better able to withstand the high temperatures. It is suggested that stainless steel flights be used over the entire length of the stoker auger in future models.

6.3.9.2 Ash handling

As discussed in section 4.3.1, ash removal from the combustion chamber was largely ineffective in that the material did not move to, let alone pass through, the ash discharge port. In an attempt to remedy this problem the stoker auger was modified when the stainless steel flights were added (section 6.3.8.1) by extending the flights as a centreless helix running through the length of the combustion chamber and ending at the ash port. Concern existed that this modification might interfere with the ignition process by moving fuel straight through the chamber and preventing it from reaching the ignition element. Limited tests indicated that ignition was unaffected and that it remained possible to obtain a hot fire as before. It is suggested that use of a centreless, stainless steel auger running through the combustion chamber be considered in future versions of the Heat Harvester in order to remove ash and clinkers and so maintain combustion chamber cleanliness.

6.4 Storage-to-hopper handling system

The mechanical fuel handling system installed for use with the Heat Harvester has in fact been used with a Skogma stoker because of the large number of problems encountered with the Heat Harvester. The system appears to work well, although experience with it has been limited and therefore it is premature to draw conclusions relative to its long-term reliability. It is recommended that further testing be undertaken to determine the range of particle sizes and other fuel characteristics that can be accommodated. Also, questions remain relative to the maximum distance over which the modified flexible auger system can operate, and a test program to determine this would help assess the general applicability of the system.

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2. Roberts, J., and F. Austin, A. T. Rosano, J. Willenberg. "Measuring and Improving The Efficiency of Large Wood-Fired Furnaces: Impact On Emissions and Fuel Use". Proc. Int. Conf. Residential Solid Fuels. Portland, OR. 1981.

3. Short, C. A. "Effect of Fuel Characteristics On The Performance Of A Heat Harvester TB500H Combustion System". DSS File No. 20ST.23216-5-7047. 1986.

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APPENDIX I

MANUFACTURER'S BROCHURE

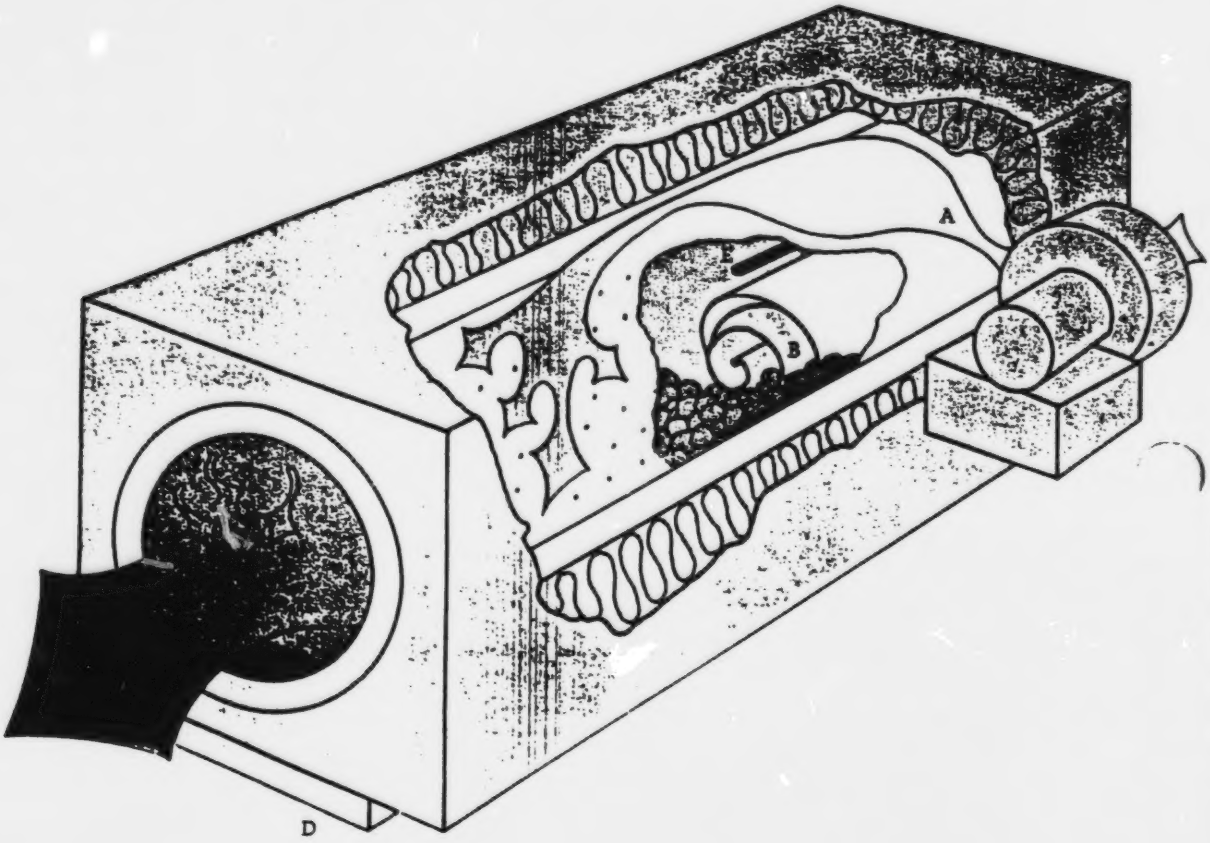
HEAT HARVESTER
TB 500

[illegible] Combustion [illegible]

- Hospitals
- Schools
- Product Dryers
- Farms
- Greenhouses
- Job Shops
- Factories

- Automatic start and feed
- Automatic switch to backup fuel
- Automatic ash removal
- Easy installation on existing equipment
- 2-4 year payback

The **TB 500** is an advanced solid fuel combustion system specifically designed for attaching to existing oil or gas fired furnaces, boilers or dryers



Advanced Features

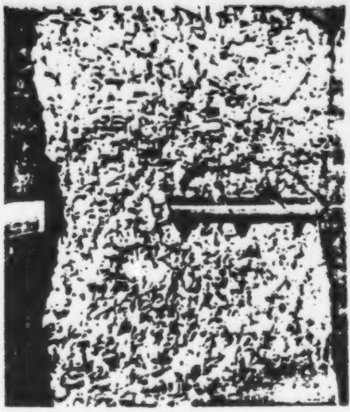
This solid fuel burner is highly efficient, convenient to install and operate and has low air pollution emissions. Its innovative engineering design features include

A.
Preheating of combustion air
B.
Predrying and gasification of fuel in combustion chamber
C.
High turbulence through forced combustion air jets
D.
Automatic ash removal
E.
Electric starter coil

Fuel Variety

A variety of inexpensive fuels can be effectively used

- Dry wood chips
- Green wood chips
- Wood pellets
- Wood cubes
- Wood shavings
- Grass pellets
- Peat pellets
- Paper waste cubes
- Nut shells
- Nut hulls
- Pelletized agricultural wastes



Low Cost Installation

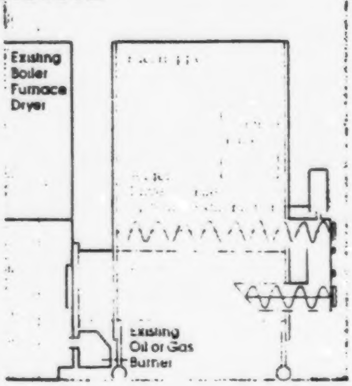
The self-contained unit is easily installed.

- Prewired motors and control panel
- Utilizes existing thermostat fan and other controls
- Present burner is maintained for backup heat

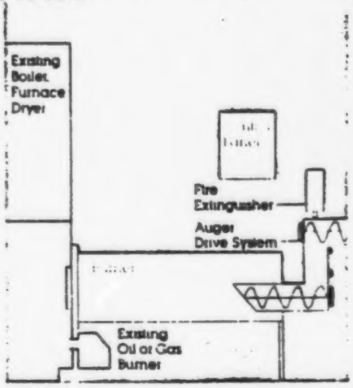
Two models to fit any installation

- TB 500H includes an overhead metering fuel hopper to save floor space
- TB 500 accepts fuel fed from a user supplied hopper in-line with the burner

TB 500H


Existing Boiler Furnace Dryer
Existing Oil or Gas Burner

TB 500


Existing Boiler, Furnace Dryer
Fire Extinguisher
Auger Drive System
Existing Oil or Gas Burner

asy Operation

The TB 500 control panel provides

- Automatic fuel feed
- Automatic ignition
- Automatic high temperature shutdown
- Automatic switch to backup fuel
- Continuous temperature readout
- Function indicator lights
- Easy adjustment of fuel/air mix for different fuels

Saves Money

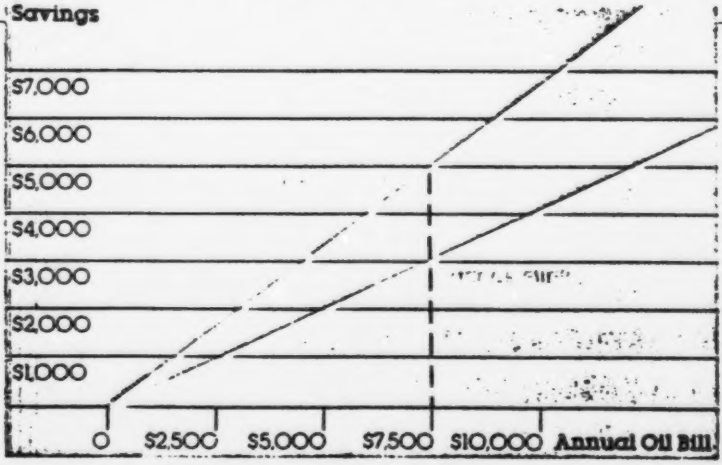
If your annual oil bill is $7500 the TB 500 will save you $5000 per year if green wood chips are used or $3000 using wood pellets.

Typical Fuel Costs

#2 Oil:
$1.00/gallon

Green Wood Chips
$15.00/ton

Wood Pellets
$70.00/ton



Features

Burner

- Stainless steel combustion chamber
- Electric starter coil
- Sight glass
- Heavy duty ceramic insulation with steel jacket
- Ash drop with flange for receptacle
- Radial vane blower

Controls

- Automatic [illegible]
- [illegible]
- Automatic [illegible]
- Automatic changeover to backup fuel system
- On off cycling or modulating fuel delivery

Safety

- [illegible] auger system
- [illegible] of all components to reduce false draft
- Built in dry chemical fire extinguisher
- Heavy duty insulation
- High temperature cut off

Optional

- Ash auger
- Thermally activated damper

Specifications

Capacity

300 000 - 600 000 BTU/hr
depending on fuel

600 000 - 1 200 000 BTU/hr
for TB 1000 [illegible]

Burner Dimensions

Flange size 17" x 17"

Overall length 51" including auger drive

Diameter of heat discharge 10"

Auger Drive System

Variable speed DC gear motor

High constant torque capacity

Electrical

110V 20FLA

Fuel Hopper (TB 500H)

Overall dimensions 36" l x 25" w x 48" h without legs

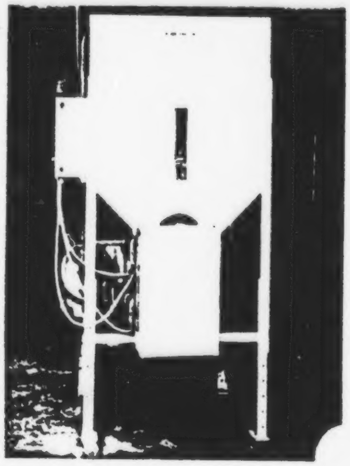
4 legs with casters adjustable to height of 32"

Capacity 19 cubic feet
(3-5 [illegible] hours depending on fuel)

Weight

TB 500 250 lbs

TB 500H 450 lbs



Heat Harvester Corporation
PO Drawer D
Carrboro NC 27510
(919) 929 5857

APPENDIX II

MANUFACTURER'S OPERATING INSTRUCTIONS

C. CONTROL PANEL

1. SEQUENCE OF OPERATION

Cold Start	TB_1 below set point boiler/furnace calling for heat; S_1 set on TB	R_1 closes 3 & 6, power to starter; T_1 starts timer on auger interupt T_3 starts timer on switch-over to back-up burner and/or alarm;
Hot Start/ Normal Oper.	TB_1 above set point boiler/furnace calling for heat; S_1 set on TB	breaks power to R_1; power to R_2 ,auger and fan;
Shut Down	TB_1 above set point boiler/furnace no longer calling for heat; S_1 set on TB	power to L_1 and S_1 cut; auger off, fan on timer T_2 to interupt and reset
Cold Start	TB_1 below set point boiler/furnace calling for heat; S_1 set on TB; T_3 ellapsed	power to Aux. Burner/Alarm through 1 & 3 on T_3 and 1 & 3 on R_3; power off by 6 & 5 on R_3, power off to R_1
Normal Oper.	TB_1 above set point; TB_2 above set point boiler/furnace calling for heat; S_1 set on TB	breaks power to auger on TB_2; power to auger after temp. drop of 150 °F

2. Legend to Wiring Diagram

TB_1 : temperature controller, remote thermocouple - cold start/normal oper. sequencer

$_2$: temperature controller, remote thermocouple - high temp. limit to prevent over-firing the burner and exceeding temp. for steel

T_1 : timed on-relay (range:10 - 480 sec.) - initial fuel feed during cold start

T_2 : timed off-relay (range:3 - 300 sec.) - delayed off of combustion air fan for good burn-out

T_3 : timed off-relay (range:10 - 5120 sec.) - delayed off of cold start sequence and conect of aux. burner and/or alarm

R_1 : common DPDT switch relay - controls starter coil and auger

R_2 : common DPDT switch relay - controls auger and fan

R_3 : common DPDT switch relay - controls aux. burner and/or alarm

F_1 : line fuse FNM-10, 250V or less, SC 10kA, 125V - protects fan

F_2 : line fuse FNM-10, 250V or less, SC 10kA, 125V - protects other loads

DC-SCR : Auger motor control - adjustable fuel feed rate, firing rate

Contact ratings: TB_1 &TB_2 15A, all others 10A

3. Connections on Terminal Strip

L_1 & L_2 : constant power for fan & T_2, 115V, L_2 = neutral

1 : hot wire from boiler/furnace controls or thermostat

2-1
2-2 : neutrals for all loads
2-3

2-4 : fan neutral

3 : back-up burner remote or alarm

4 : no load

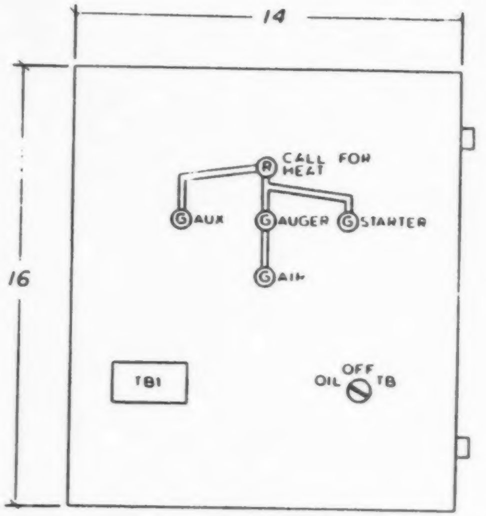
5 : no load, internally wired to TB_1

[illegible] : starter coil, hot AC

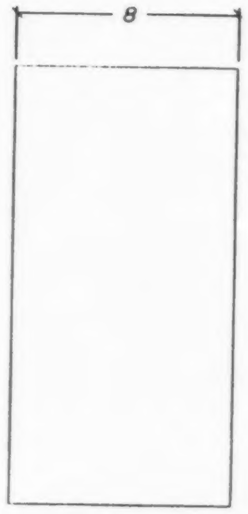
8 : fan, hot AC

DC_1 : DC +, gear motor, auger

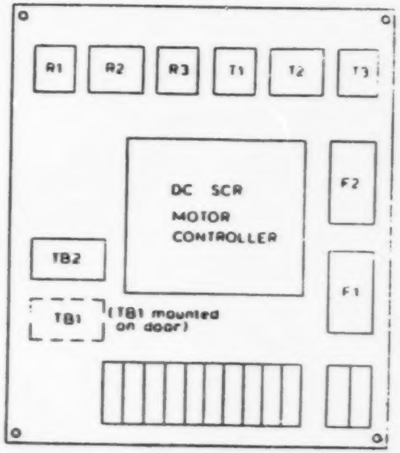
DC_2 : DC -, gear motor, auger


14
16
CALL FOR HEAT
R
G AUX
G AUGER
G STARTER
G AIR
TB1
OFF
OIL
TB

FRONT VIEW



SIDE VIEW


R1
R2
R3
T1
T2
T3
DC SCR MOTOR CONTROLLER
F2
F1
TB2
TB1
(TB1 mounted on door)

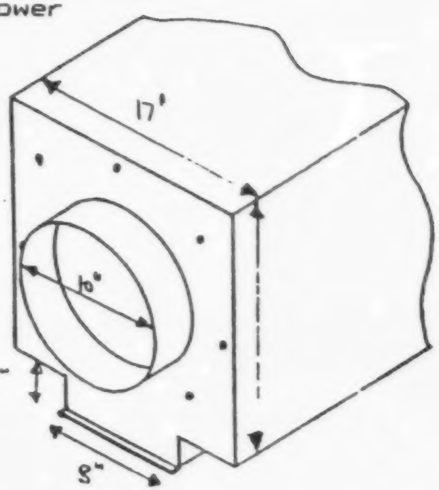
PANEL LAYOUT

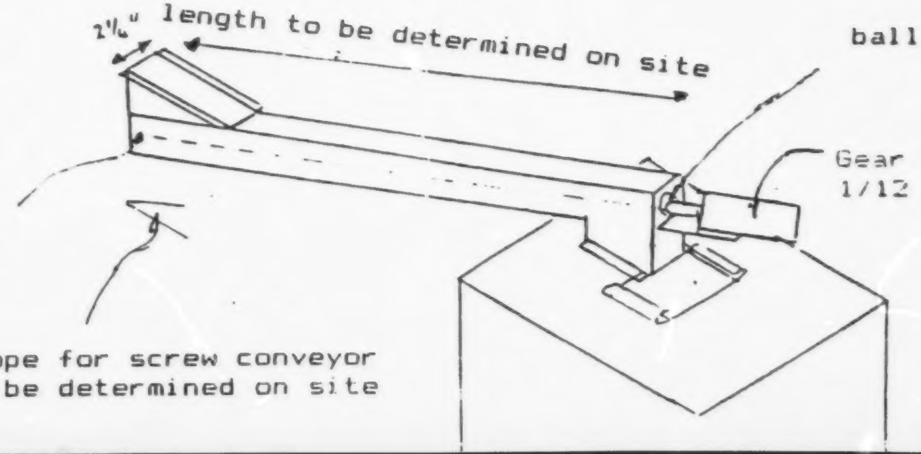
TOLERANCES (EXCEPT AS NOTED)	REVISIONS					
	NO	DATE	BY	HEAT HARVESTER CORP		
DECIMAL ±	1			PANEL LAYOUT		
FRACTIONAL ±	2					
	3			DRAWN BY	SCALE	MATERIAL
ANGULAR ±	4			CHK'D	DATE	DRAWING NO
	5			TRACED	APP'D	

Dept. of Forest Engineering
SEP 20 1984
University of New Brunswick

For adapter plate

- inner burner shell I.D. 10", 12 ga, SS309
- flange size 17" x 17"
- holes to be drilled after making template from burner flange
- seal between burner flange and adapter plate flange with high temperature silicone
- lowest possible centre line level for tunnel : 10" above lower edge of ash drop



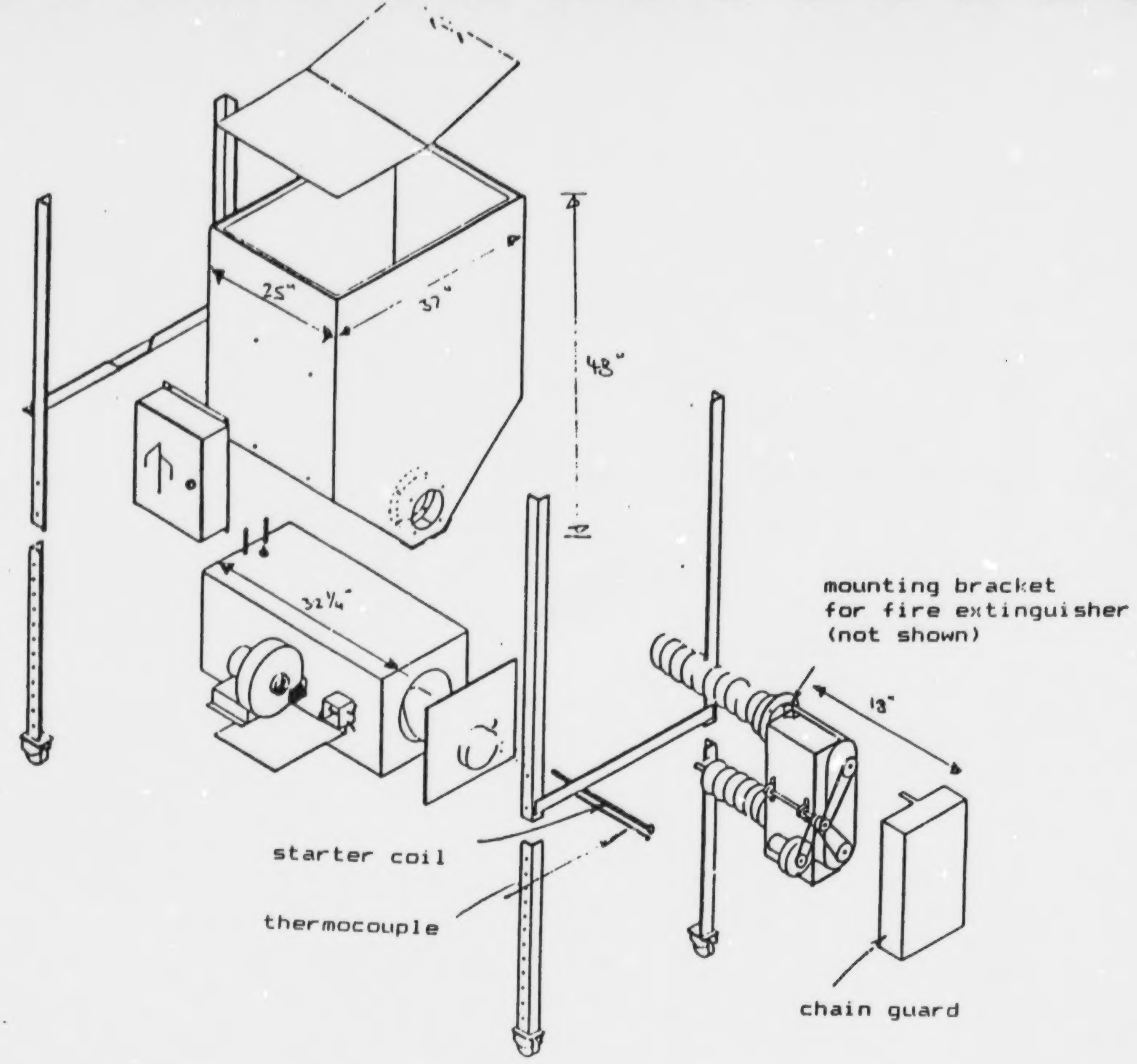


ball bearing

Gear Motor, 90VDC or 115AC
1/12 HP, about [illegible]

- use 2 1/2" chicken-feed screw conveyor
- no bearing at this end

slope for screw conveyor to be determined on site


25"
37"
48"
32¼"
13"
mounting bracket
for fire extinguisher
(not shown)
starter coil
thermocouple
chain guard

APPENDIX III

BOILER MANUFACTURER'S BROCHURE

CTC

self-reliant home-comfort with Swedish made WOOD-OIL BOILERS

From Sweden – the land of
the long cold winters

CTC BOILER 450 - SIDE VIEW

Domestic Water Production

Accomplished by means of cold water flowing through a coil of finned copper tube. With this system your faucets immediately deliver abundant hot water that is fresh, hot and clean. Should the coil become clogged by deposits of calcium for instance, it can be easily cleaned or replaced.

In hard water areas boilers with integral stainless steel cylinders for hot water are recommended (designated type R).

Double Doors

One door is provided for the oil burner and one for solid fuel. Each door is hinged separately, thus making the change over from solid fuel to oil or from oil to solid fuel quick and easy.

Large solid fuel door provides excellent access for wood firing.

Self-reliant Combustion Chamber

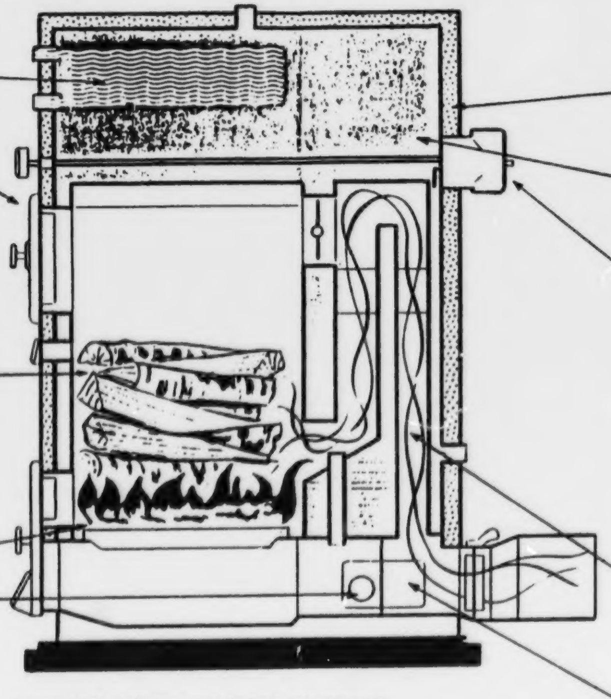
The generously sized combustion chamber gives a long firing period when using wood or coke. Various sizes of logs can be used dependent upon boiler size. The large size of chamber gives excellent results when oil-firing and reduces combustion noise. The combustion surface area is designed to maximise boiler efficiency: too small a chamber would mean more frequent filling, too large a chamber can give rise to tar-like deposits with certain fuels.

Under-fire System

The boiler design ensures that a complete refueling of timber does not burn away too quickly and ensures even heat between refuelings. This factor combined with the minimum air device eliminates the formation of tar and soot deposits as may be experienced with other wood burning appliances.

Secondary Air Supply

A high proportion of the heat energy available in the wood is released from the top of the flame area in the form of unburnt gases. To burn away these gases the boiler adds secondary air thus ensuring that full burning of all combustible materials takes place almost completely, maximising efficiency and minimising combustion surface deposits.



An established design suitable for future demands

Although originally designed during the 40's the CTC 450 boilers can be incorporated into all modern heating systems, particularly where supplementary or stand-by heating is desirable. The 450 Series boilers provides a self-reliant heating unit in as much as if your regular oil supply fails timber and coke can be utilised to fire the boiler. Alternatively, if you have timber available on a regular basis the unit can provide your heating requirements without burning up increasingly expensive oil.

Satellite Boiler

450 Series boilers are available without the domestic hot water facility. In this form they are suitable as a money-saving unit installed side by side with your existing oil or gas fired boiler. They can thus be put into service at any time utilising wood or other solid fuel.

Insulation

The boilers are heavily insulated. Minimum thickness 40 mm. This prevents heat loss and increases boiler economy. Even the front boiler doors are heavily insulated.

Boiler Water Content

The large water content of the boiler ensures long periods of oil burner operation and of stand-stills, thus giving economical burner operating conditions. The large water content also provides additional capacity for the production of domestic hot water.

Built-in Mixing Valve

The mixing valve adjusts the temperature of the water in the house heating system in accordance with outside temperature conditions whilst maintaining the boiler water at the optimum level most suitable for efficient operation of the boiler and the production of domestic hot water.

The mixing valve also blends the return flow with high temperature boiler water before it contacts the boiler heating surface thus reducing thermal shock and increasing the life of the boiler.

Additional Connections

Additional connections are provided as standard for a secondary circulation system or to give swimming pool heating.

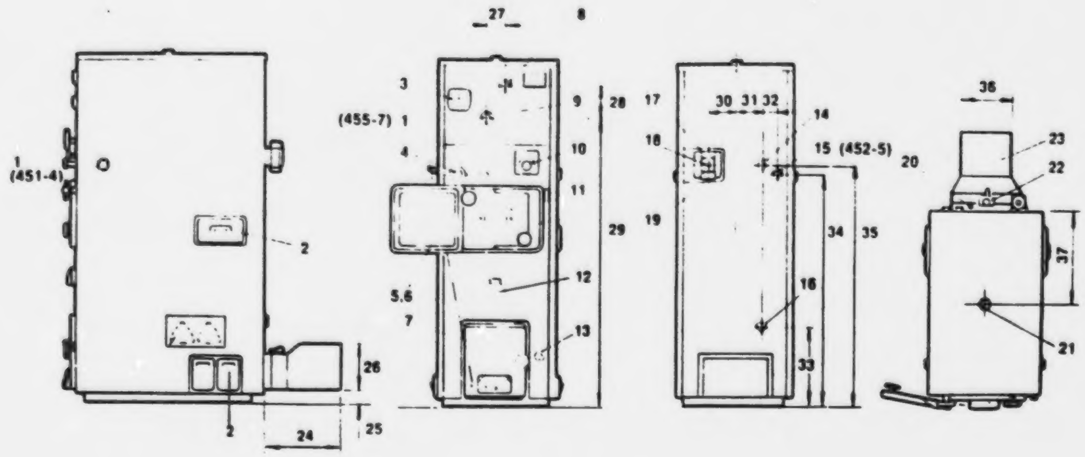
Long flue passages

The extensive secondary heating surfaces, all of which are surrounded by boiler water, effectively utilise all combustion heat produced by the fuel. They also ensure complete combustion of all solid fuel particles which consequently cannot enter into the chimney.

Cleaning Doors

Cleaning doors are situated on both sides of the boiler enabling cleaning to be carried out easily and effectively. All secondary heating surfaces can be cleaned from these doors whilst the combustion chamber is easily accessible via the front doors.

Type	Efficiency/h						Domestic Water Capacity						Main dimensions						Combustion chamber						Content		Inner Filling Door Dimensions				Boiler Water Content		Weight	
	Oil/gas		Coke		Wood		Flow/min		Tot flow and med temp				Width		Depth		Height		Width		Depth		Height				Width		Height					
	Mcal	BTU	Mcal	BTU	Mcal	BTU	L	Am gall	L	Am gall	C	F	MM	In.	MM	In.	MM	In.	MM	In.	MM	In.	MM	In.	L	Am gall.	MM	In.	MM	In.	L	Am gall.	Kos	Pounds
451 B	23	90'	18	72'	15	59'	30	7.9	200	52.8	42	107	544	21 27/64	852	33 35/64	1370	53 15/16	340	13 3/8	400	15 3/4	580	22 53/64	80	21	300	11 13/16	240	9 29/64	215	56.8	320	704
452 B	32	126'	25	98'	21	83'	30	7.9	200	52.8	45	112	544	21 27/64	852	33 35/64	1470	57 7/8	340	13 3/8	400	15 3/4	750	29 17/32	100	26	300	11 13/16	240	9 29/64	230	60.7	345	760
453 B	45	180'	36	142'	30	118'	45	11.9	250	66.1	45	112	670	26 3/8	1076	42 23/64	1446	56 59/64	510	20 5/64	600	23 5/8	750	29 17/32	215	56	300	11 13/16	240	9 29/64	300	79.2	470	1,035
454 B	65	255'	50	198'	42	165'	45	11.9	400	105.7	42	107	670	26 3/8	1076	42 23/64	1646	64 13/16	510	20 5/64	600	23 5/8	950	37 13/32	275	72	300	11 13/16	240	9 29/64	320	84.5	545	1,200
455 B	95	375'	72	285'	60	235'	50	13.2	400	105.7	45	112	830	32 43/64	1106	43 35/64	1794	70 5/8	670	26 3/8	600	23 5/8	1000	39 3/8	400	105	300	11 13/16	240	9 29/64	440	116.2	595	1,310
456 B	130	515'	96	380'	80	315'	63	16.6	600	158.5	47	117	986	38 53/64	1237	48 45/64	1770	69 11/16	820	32 9/32	600	23 5/8	960	37 51/64	460	121	355	13 31/32	405	15 15/16	630	166.4	840	1,850
457 B	160	630'	120	475'	100	395'	63	16.6	600	158.5	50	123	986	38 53/64	1362	53 5/8	1985	78 9/64	820	32 9/32	700	27 9/16	1160	45 43/64	640	169	355	13 31/32	405	15 15/16	730	192.8	1050	2,312



DIMENSIONS

		451		452		453		454		455		456		457	
1	Connection thermostat	3/4"				3/4"				3/4"		3/4"			
2	Cleaning doors														
3	Connection hydrothermometer	1/2"				1/2"				1/2"		1/2"			
4	Draught adjuster. To the right on 456, 457	3/4"				3/4"				3/4"		3/4"			
5	Solid fuel door														
6	Oil burner door, burner opening dimensions	Ø 120 mm 4 23/32 in				Ø 120 mm 4 23/32 in				Ø 120 mm 4 23/32 in.		Ø 120 mm 4 23/32 in.			
7	Grate door											Two-piece door			
8	Connection domestic hot water	3/4"				1"				1 1/4"		1 1/2"			
9	Connection cold water intake	3/4"				1				1 1/4"		1 1/2"			
10	Regulator of heating system temperature														
11	Handle for by-pass valve														
12	Flame control eye														
13	Boiler emptying point	1/2				3/4				3/4		3/4			
14	Connection secondary heating water feed	1 1/4				1 1/4				1 1/4		2"			
15	Connection over-temperature fuse	3/4 Not included in 451				3/4				3/4"		Not included			
16	Connection secondary heating water return	1 1/4				1 1/4				1 1/4"		2			
17	Connection main heating water feed	1 1/4				1 1/2				2		Ø 89/82.5 mm Ø 3.504/3.247 in			
18	Mixing valve for main heating water											Not included			
19	Connection main heating water return	1 1/4				1 1/2"				2		Ø 89/82.5 mm Ø 3.504/3.247 in			
20	Connection point smoke gas analyzer	1/8				1/8				1/8		1/8"			
21	Connection expansion tank	1 1/4"				1 1/4				1 1/4"		1 1/4"			
22	Flue draught adjuster														
23	Flue outlet	180 × 180 mm ext 7 5/64 × 7 5/64 in				266×216 mm ext (W×H) 10 15/32 × 8 1/2 in				266×216 mm ext (W×H) 10 15/32 × 8 1/2 in		295×295 mm ext 11 39/64 × 11 39/64 in			
24		240	9 29/64	240	9 29/64	385	15 5/32	385	15 5/32	385	15 5/32	425	16 47/64	425	16 47/64
25		45	1 49/64	45	1 49/64	50	1 31/32	50	1 31/32	50	1 31/32	13	1/2	13	1/2
26		180	7 5/64	180	7 5/64	216	8 1/2	216	8 1/2	216	8 1/2	301	11 27/32	301	11 27/32
27		80	3 5/32	80	3 5/32	116	4 9/16	116	4 9/16	76	2 63/64	76	2 63/64	76	2 63/64
28		137	5 25/64	137	5 25/64	138	5 27/64	138	5 27/64	205	8 5/64	205	8 5/64	205	8 5/64
29		1135	44 11/16	1235	48 5/8	1189	46 13/16	1390	54 23/32	1463	57 19/32	1452	57 11/64	1667	65 5/8
30		145	5 45/64	145	5 45/64	200	7 7/8	200	7 7/8	230	9 1/16	300	11 13/16	300	11 13/16
31		110	4 21/64	110	4 21/64	150	5 29/32	150	5 29/32	100	3 15/16	180	7 5/64	180	7 5/64
32		–	–	100	3 15/16	110	4 21/64	110	4 21/64	115	4 33/64	–	–	–	–
33		502	19 49/64	502	19 49/64	368	14 31/64	368	14 31/64	433	17 3/64	480	18 57/64	480	18 57/64
34		–	–	1037	40 53/64	1066	41 31/32	1268	49 59/64	1363	53 21/32	–	–	–	–
35		972	38 17/64	1072	42 13/64	1086	42 3/4	1288	50 45/64	1403	55 15/64	1325	52 11/64	1540	60 5/8
36		180	7 5/64	180	7 5/64	266	10 15/32	266	10 15/32	266	10 15/32	301	11 27/32	301	11 27/32
37		426	16 49/64	426	16 49/64	538	21 3/16	538	21 3/16	568	22 23/64	627	24 11/16	689	27 1/8
	All metric dimensions are exact. In view of continuous development we reserve the right to alter descriptions and dimensions without prior notice.														

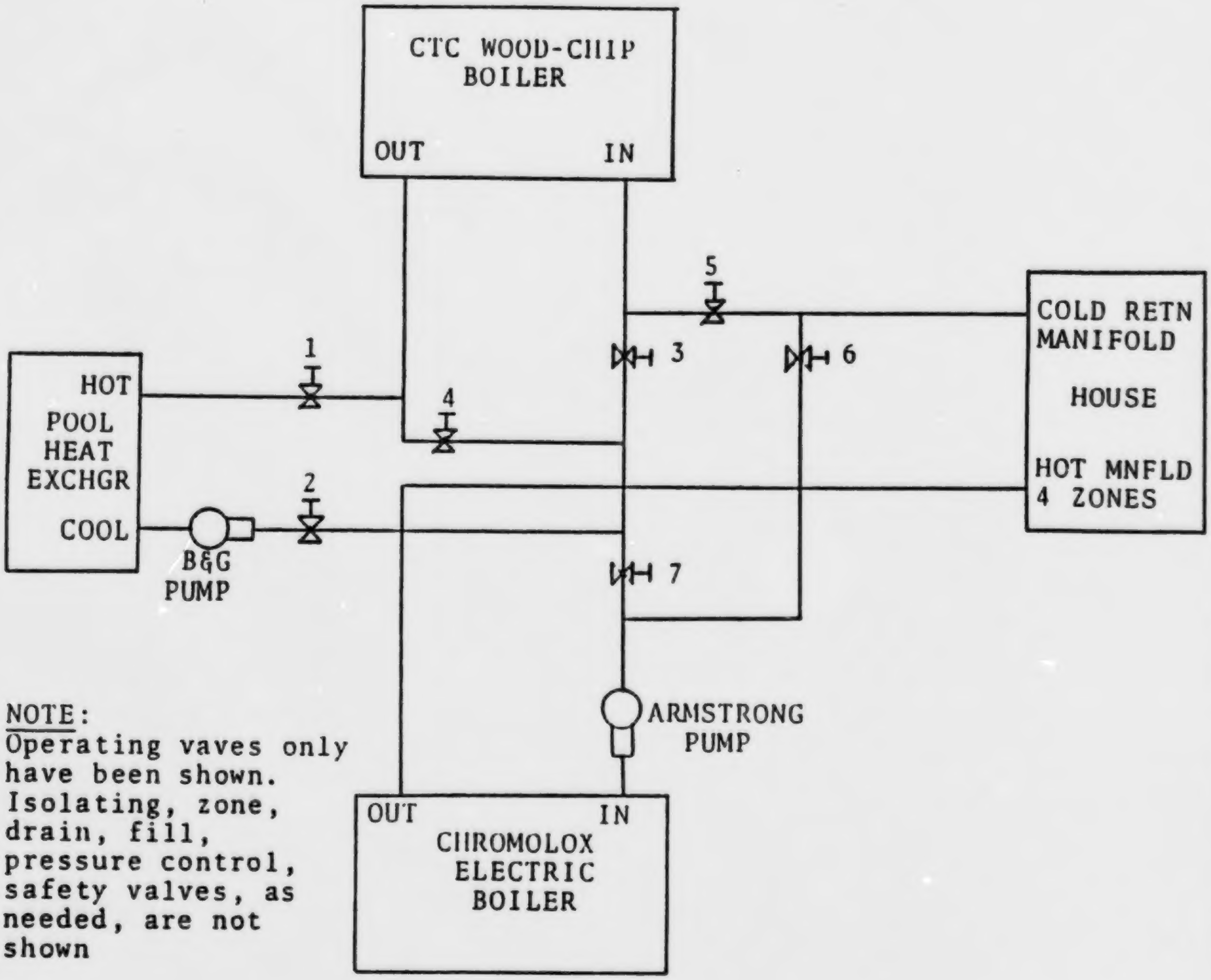
AB CTC
Box 135
S-341 00 LJUNGBY
Sweden
Tel. 0372-146 10
Telex 520 35

FORESTEC LIMITED
6393 Bayne St., Halifax, Nova Scotia
B3K 2V8
Tel: (902) 455-4062 Telex: 019-22628

Tryck AB Ljungby

APPENDIX IV

BOILER INTERCONNECTION - MECHANICAL AND ELECTRICAL


CTC WOOD-CHIP BOILER
OUT
IN
5
COLD RETN MANIFOLD
HOUSE
HOT MNFLD 4 ZONES
3
6
1
HOT
POOL HEAT EXCHGR
4
2
COOL
B&G PUMP
7
ARMSTRONG PUMP
OUT
IN
CHROMOLOX ELECTRIC BOILER

NOTE:
Operating vaves only have been shown. Isolating, zone, drain, fill, pressure control, safety valves, as needed, are not shown

TWO MODES OF OPERATION ARE POSSIBLE

1. CTC WOOD BOILER WITH ELECTRICAL BACK-UP FOR SPACE HEATING
   - this keeps the CTC boiler hot when electric heating is used. Use in winter to prevent boiler from freezing!!
   VALVES 1, 2, 3, 6 CLOSED and VALVES 4, 5, 7 OPEN: PUMP - Armstrong

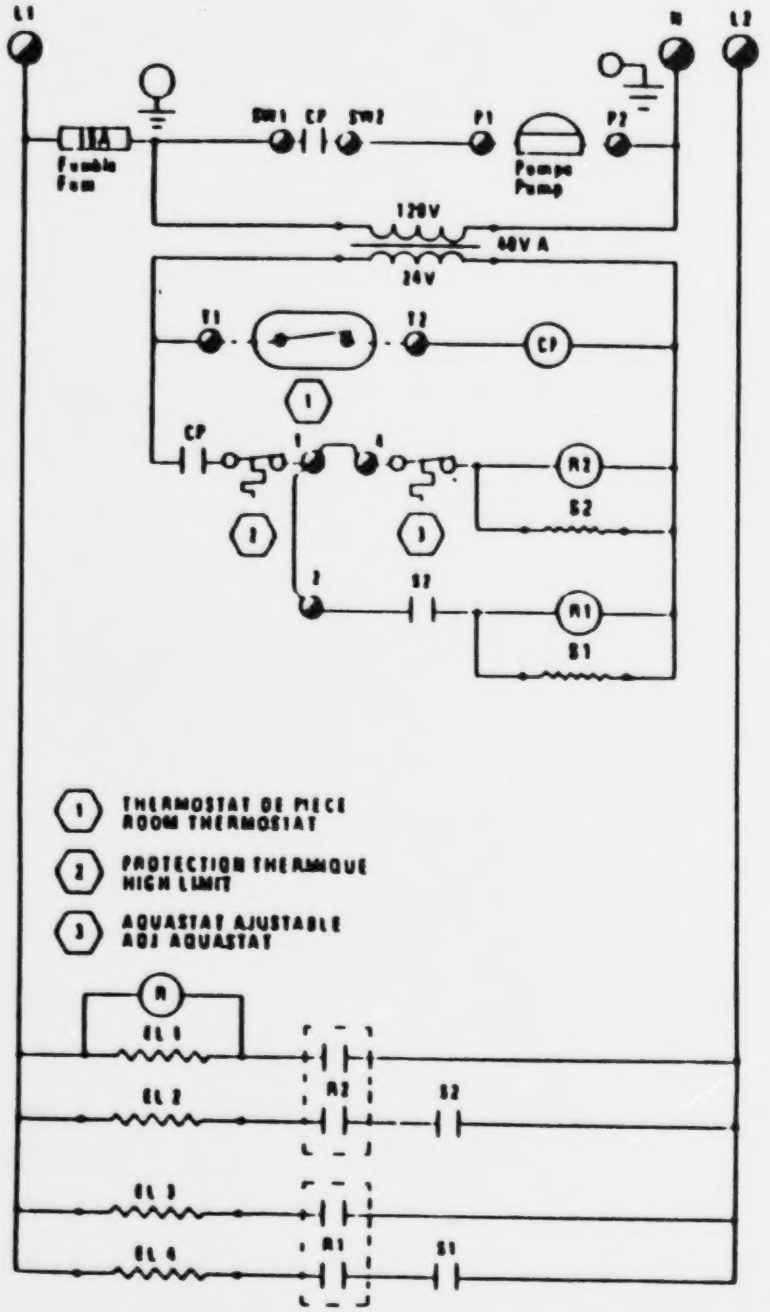
1.1 Set selector switch (behind zone valves) to electric heat only if purely electric heating is wanted.

1.2 Set selector switch to automatic electric back-up if wood heating is used and if the stoker/burner used is equipped to initiate back-up heating when/as required.

2. CTC WOOD BOILER HEAT TO POOL HEAT EXCHANGER AND ELECTRIC BOILER HEATING HOUSE
   - this does not keep CTC boiler hot unless it is being fired. Do not use if it is likely that the boiler will freeze!
   VALVES 4, 5, 7 CLOSED and VALVES 1, 2, 3, 6 OPEN
   PUMPS - Armstrong for space heat & B&G for pool heat
   Switch - electric heat only

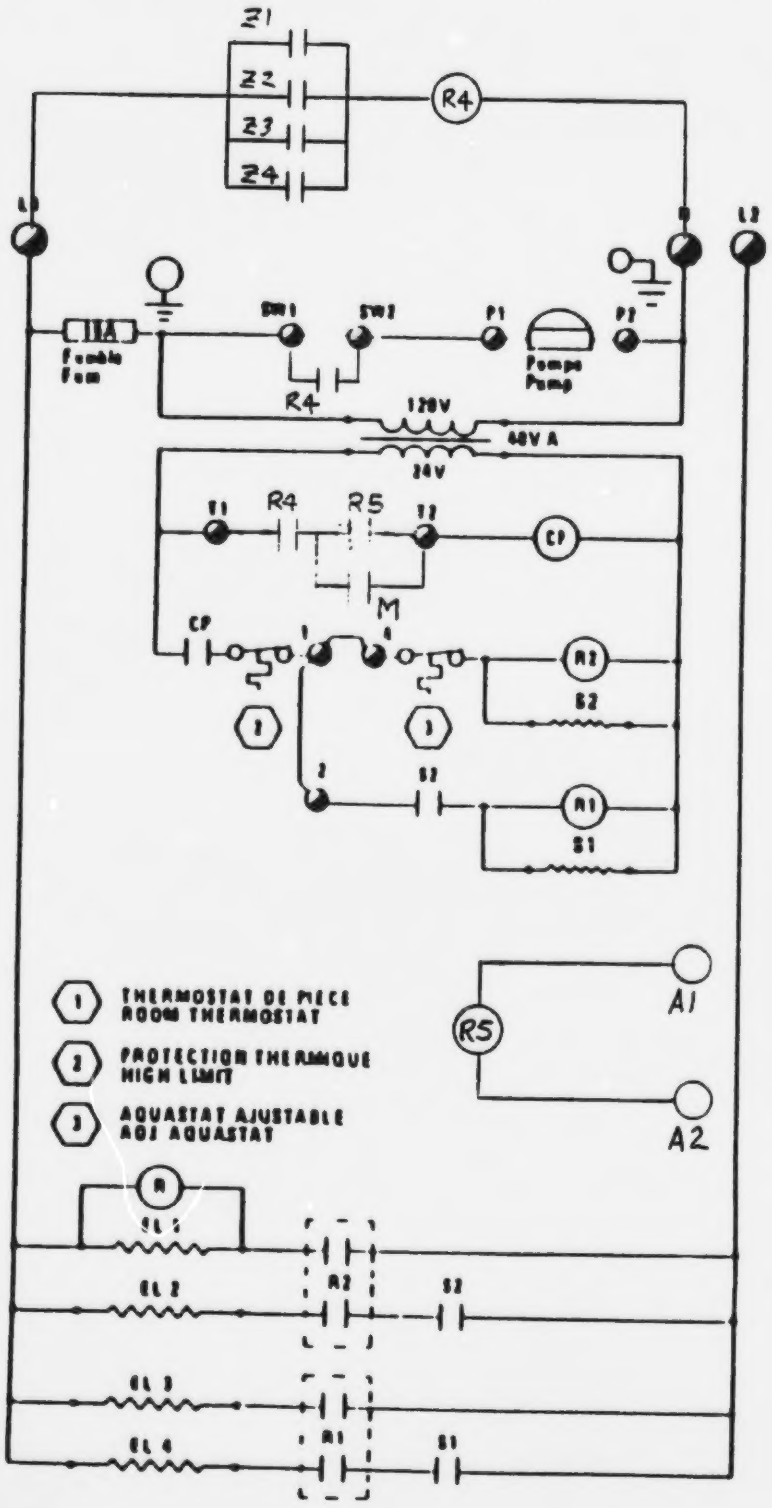
EDB-18-2, EDB-20-2

ORIGINAL CHROMALOX CONTROL


L1
N
L2
SW1
CP
SW2
P1
P2
15A
Fusible
Fuse
Pompe
Pump
120V
40V A
24V
T1
T2
CP
1
CP
1
4
R2
S2
2
3
2
S2
R1
S1
1
THERMOSTAT DE PIECE
ROOM THERMOSTAT
2
PROTECTION THERMIQUE
HIGH LIMIT
3
AQUASTAT AJUSTABLE
ADJ AQUASTAT
R
EL 1
EL 2
R2
S2
EL 3
EL 4
R1
S1

EDB-18-2, EDB-20-2

MODIFIED CHROMALOX CONTROL

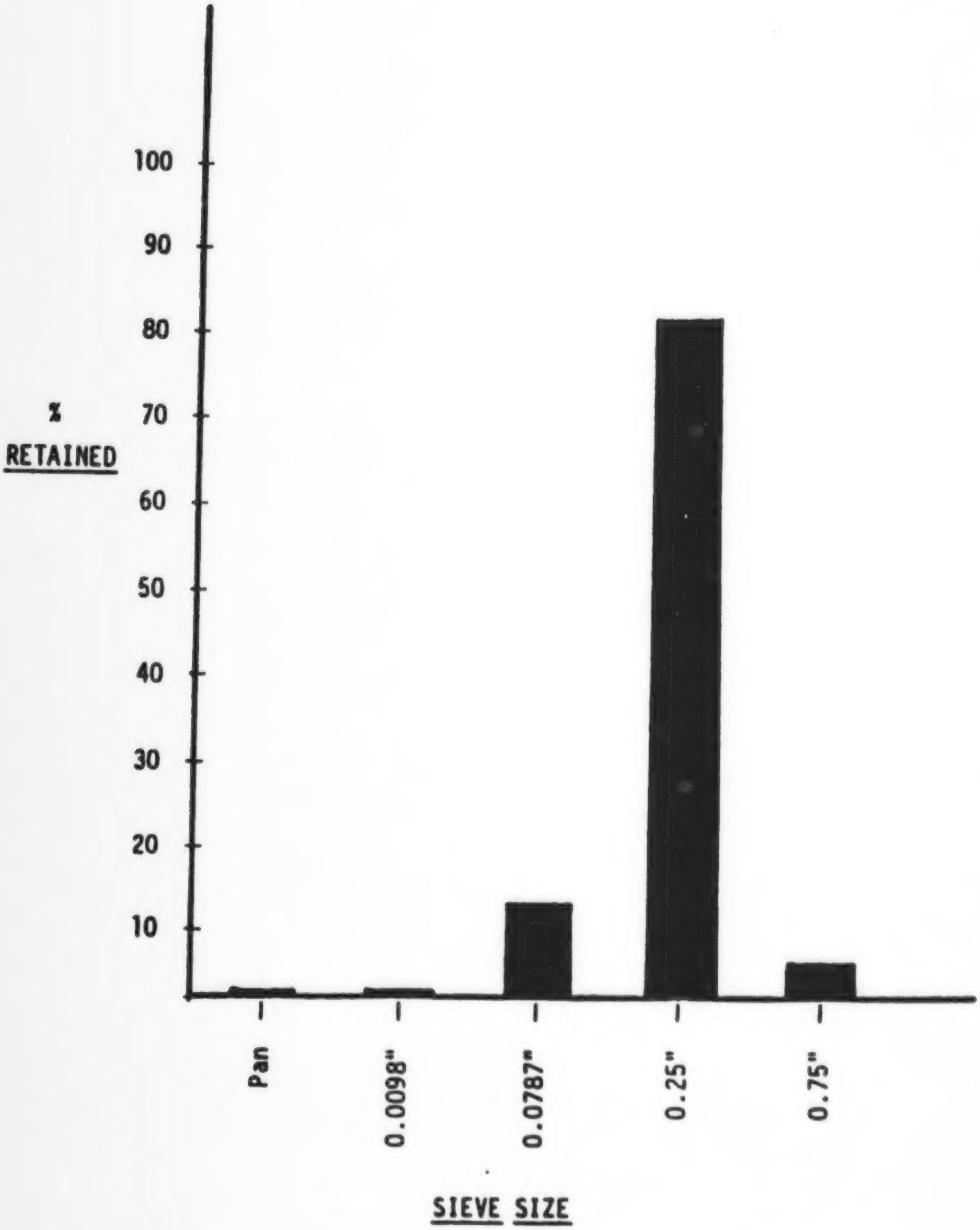

Z1
Z2
Z3
Z4
R4
L1
N
L2
15A
Fusible
Fuse
SW1
SW2
P1
P2
Pompe
Pump
R4
120V
40V A
24V
T1
R4
R5
T2
CP
M
CP
1
4
R2
S2
1
3
2
S2
R1
S1
THERMOSTAT DE PIECE
ROOM THERMOSTAT
PROTECTION THERMIQUE
HIGH LIMIT
AQUASTAT AJUSTABLE
ADJ AQUASTAT
R5
A1
A2
R
EL 1
EL 2
R2
S2
EL 3
EL 4
R1
S1

Z1 to Z4	- zone control valve end switches
A1, A2	- auxiliary output (120v) from chip burner on loss of fire
M	- manual switch. On for automatic operation of electric heat only

APPENDIX V

FUEL CHARACTERISTICS

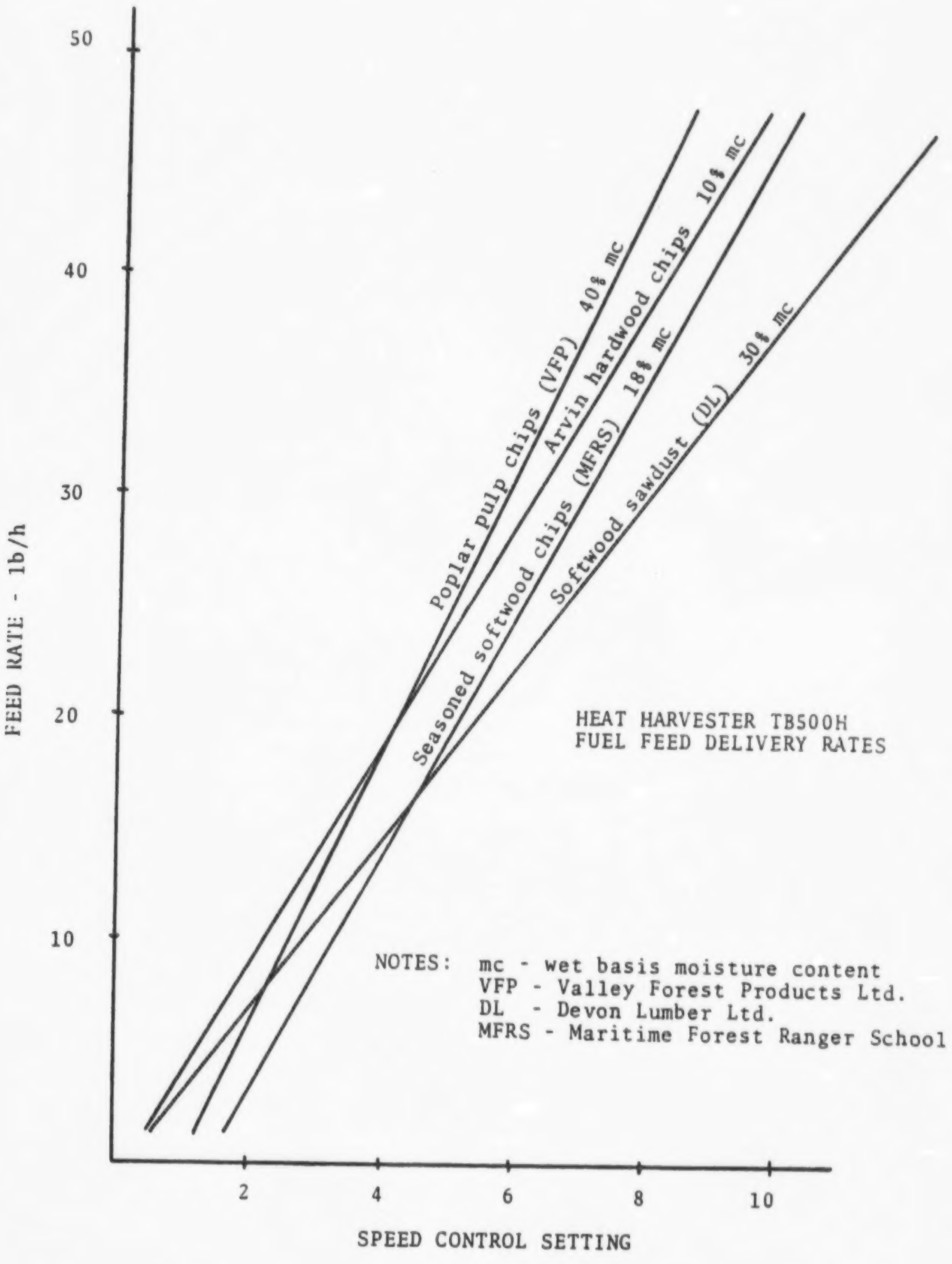
FUEL TYPE: Arvin chips (hardwood)
ORIGIN: Wilkins Mill Chipping centre
COLLECTION DATE: 85-11-11
ANALYSIS DATE: 85-11-15



SOLID FUEL SIEVE ANALYSIS

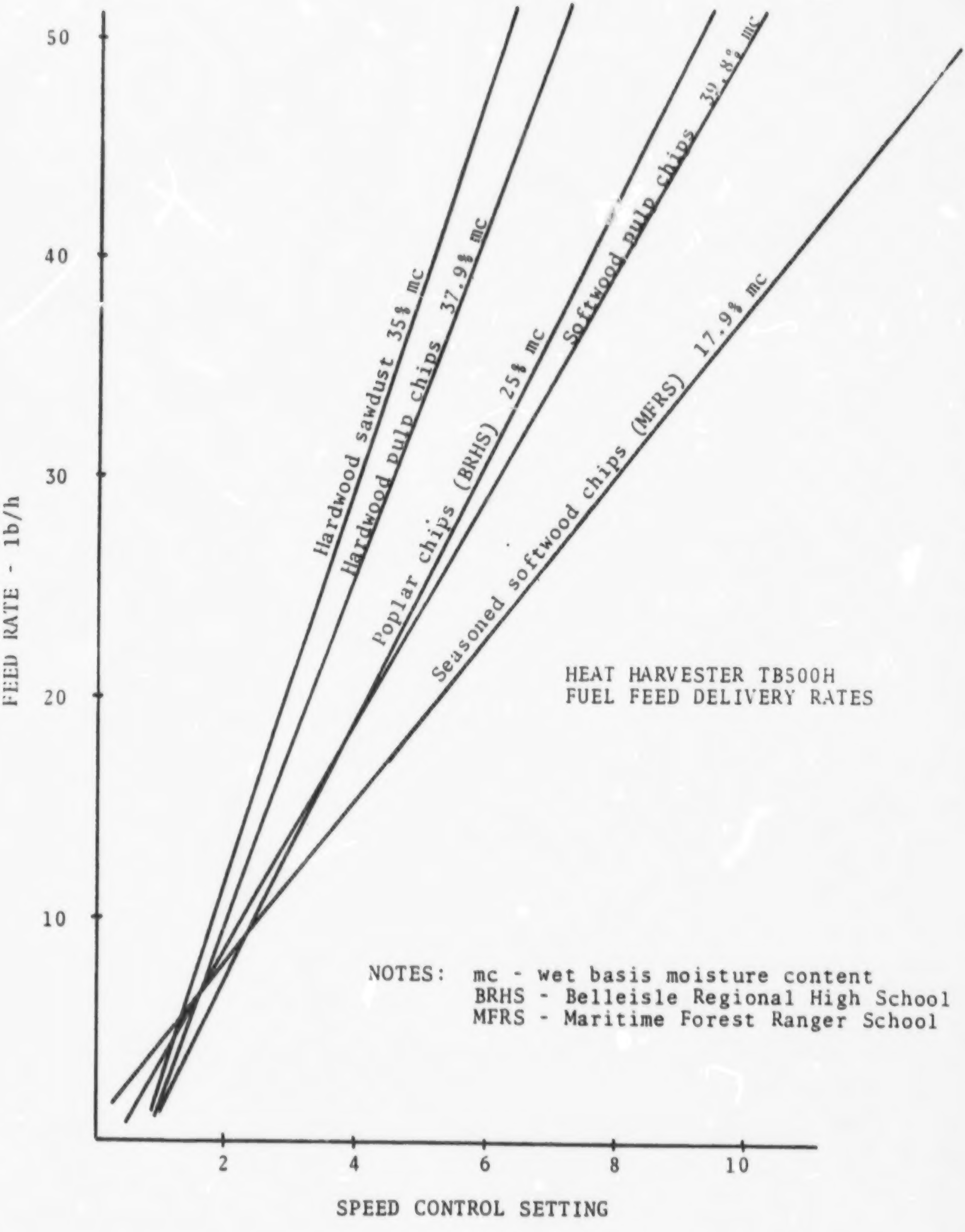
APPENDIX VI

FUEL FEED RATES

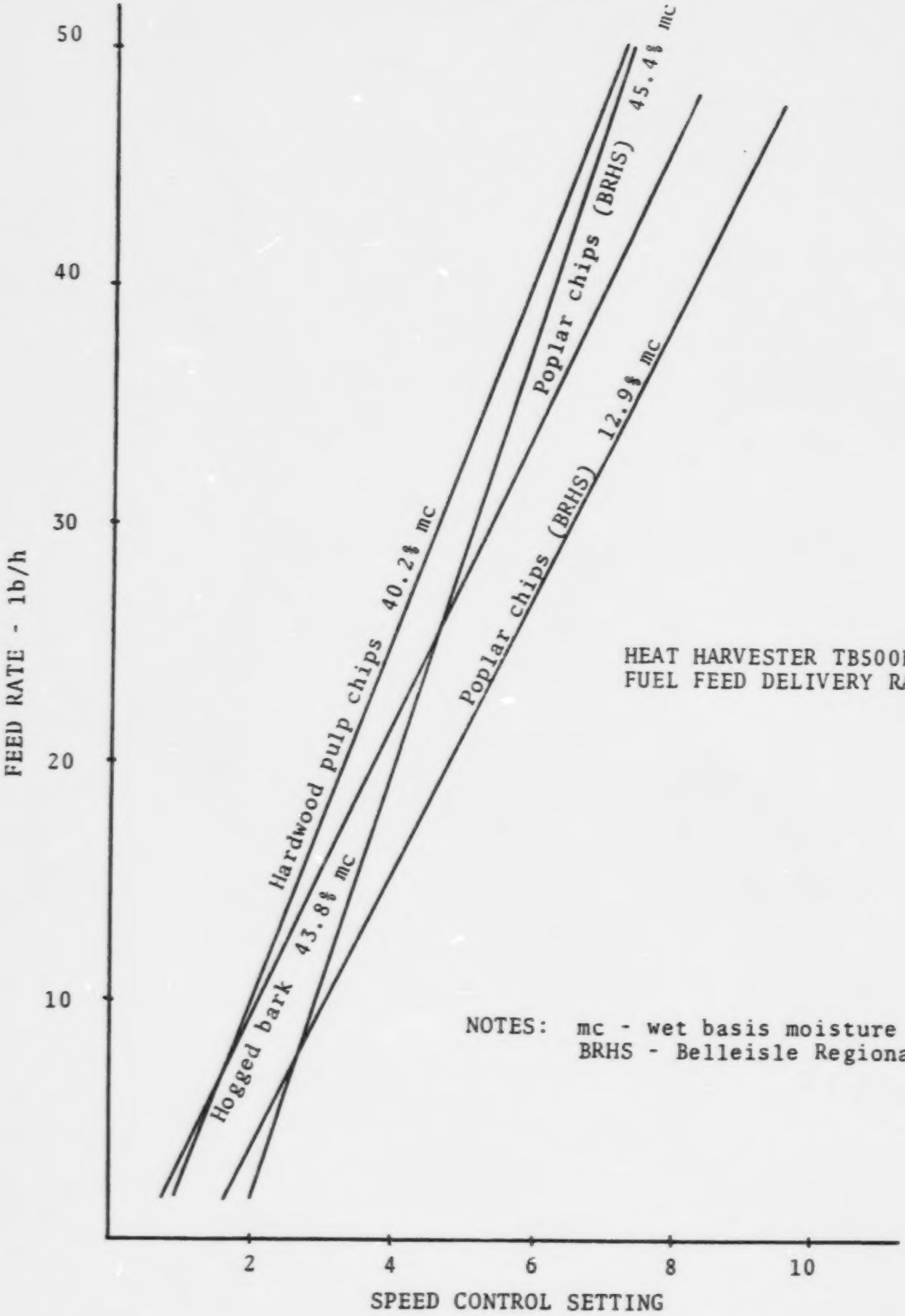


HEAT HARVESTER TB500H
FUEL FEED DELIVERY RATES

NOTES:
mc - wet basis moisture content
VFP - Valley Forest Products Ltd.
DL - Devon Lumber Ltd.
MFRS - Maritime Forest Ranger School



HEAT HARVESTER TB500H
FUEL FEED DELIVERY RATES
FEED RATE - lb/h
SPEED CONTROL SETTING
10
20
30
40
50
2
4
6
8
10
Hardwood sawdust 35% mc
Hardwood pulp chips 37.9% mc
Poplar chips (BRHS) 25% mc
Softwood pulp chips 39.8% mc
Seasoned softwood chips (MFRS) 17.9% mc
NOTES: mc - wet basis moisture content
BRHS - Belleisle Regional High School
MFRS - Maritime Forest Ranger School



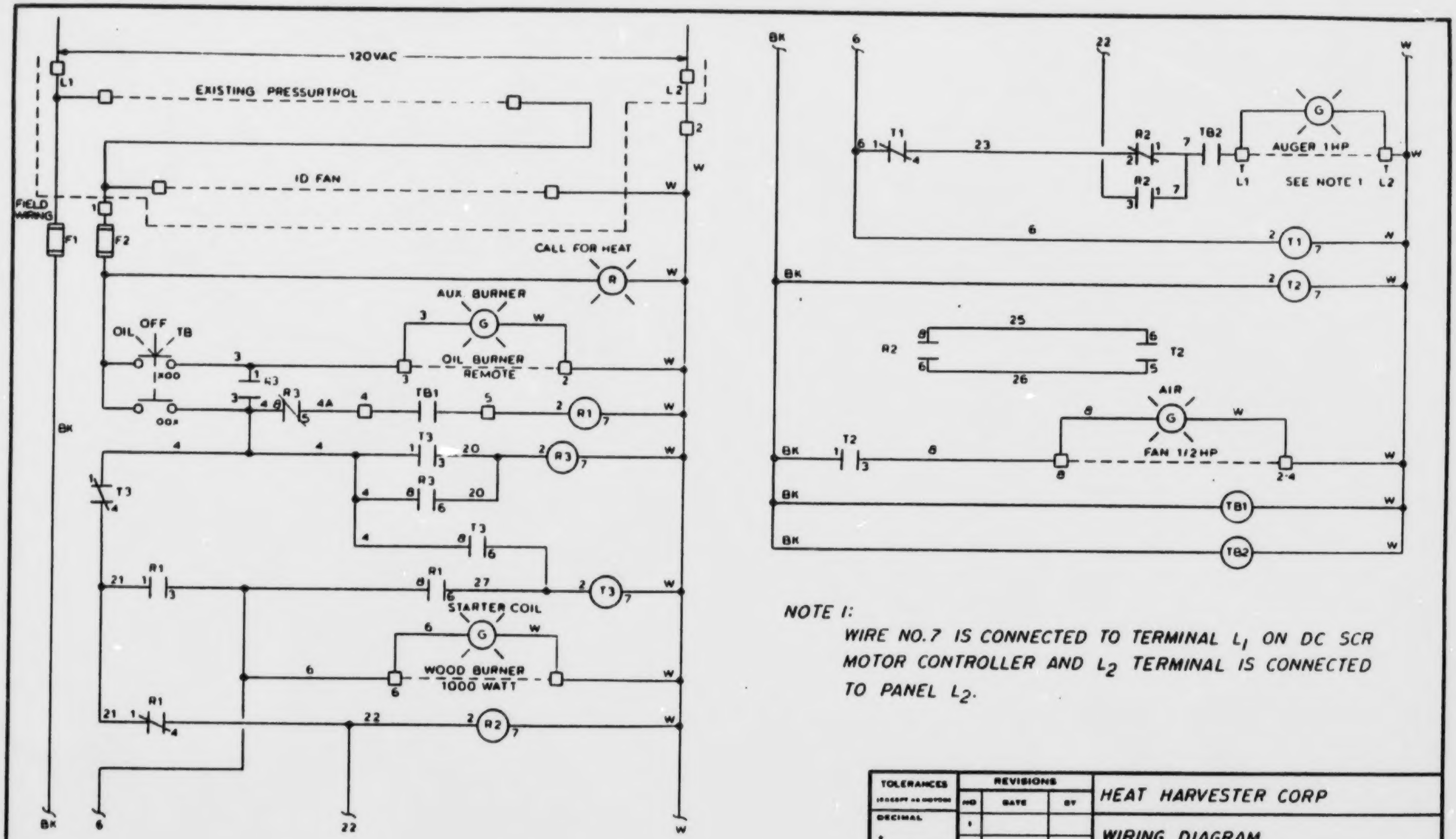
HEAT HARVESTER TB500H
FUEL FEED DELIVERY RATES

NOTES: mc - wet basis moisture content
BRHS - Belleisle Regional High Schoo

APPENDIX VII

HEAT HARVESTER WIRING DIAGRAM

ORIGINAL AND MODIFIED


120VAC
L1
L2
2
EXISTING PRESSURTROL
ID FAN
FIELD WIRING
F1
F2
1
W
BK
CALL FOR HEAT
R
AUX BURNER
G
OIL BURNER REMOTE
OIL
OFF
TB
3
2
R3
4A
4
5
TB1
R1
7
T3
20
8
6
21
27
STARTER COIL
WOOD BURNER 1000 WATT
22
R2
T1
23
TB2
AUGER 1HP
SEE NOTE 1
T2
25
26
AIR
FAN 1/2HP
2-4
TB1
TB2
6
22

NOTE I:

WIRE NO.7 IS CONNECTED TO TERMINAL L_1 ON DC SCR MOTOR CONTROLLER AND L_2 TERMINAL IS CONNECTED TO PANEL L_2.

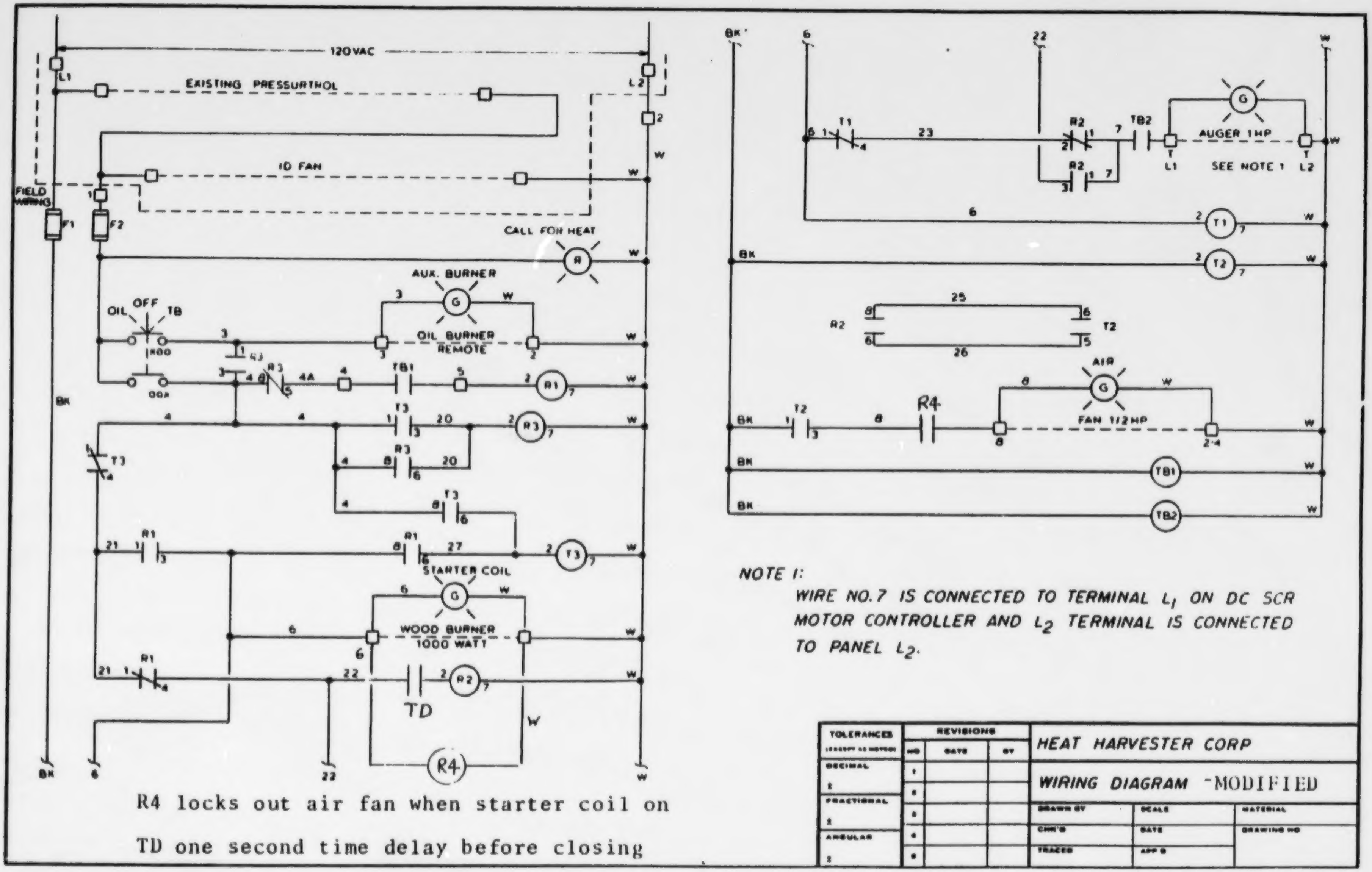
TOLERANCES (EXCEPT AS NOTED)
DECIMAL ±
FRACTIONAL ±
ANGULAR ±

REVISIONS		
NO	DATE	BY
1		
2		
3		
4		
5		

HEAT HARVESTER CORP

WIRING DIAGRAM

DRAWN BY	SCALE	MATERIAL
CHK'D	DATE	DRAWING NO
TRACED	APP'D	


120VAC
L1
L2
EXISTING PRESSURTROL
ID FAN
FIELD WIRING
F1
F2
BK
W
CALL FOR HEAT
R
AUX. BURNER
OIL BURNER REMOTE
OIL
OFF
TB
R3
TB1
R1
T3
STARTER COIL
WOOD BURNER 1000 WATT
R2
TD
R4
T1
AUGER 1HP
SEE NOTE 1
TB2
T2
AIR
FAN 1/2HP
G
21
22
23
25
26
27
20
4A

NOTE 1:
WIRE NO.7 IS CONNECTED TO TERMINAL L_1 ON DC SCR MOTOR CONTROLLER AND L_2 TERMINAL IS CONNECTED TO PANEL L_2.

R4 locks out air fan when starter coil on

TD one second time delay before closing

HEAT HARVESTER CORP

WIRING DIAGRAM -MODIFIED

TOLERANCES (EXCEPT AS NOTED)	REVISIONS		
	NO	DATE	BY
DECIMAL	1		
±	2		
FRACTIONAL	3		
±	4		
ANGULAR	5		
±			

DRAWN BY
SCALE
MATERIAL
CHK'D
DATE
DRAWING NO
TRACED
APP'D

APPENDIX VIII

DAILY PERFORMANCE RECORDS

OCTOBER 1985

DAY	TIME	CHROMALOX kW.h elec	WOOD STOVE lbs	HEAT kW.h elec	HARVESTER Monitor hrs	SPACE kW.h therm	COMMENTS
1	Heat off. Plumbing and wiring being revised to install electric						
2	boiler for automatic back-up heating and to remove oil-fired boiler						
3							
4							
5		12641.2	- initial reading 20 kW Chromalox electric boiler				
6	Readings not taken						
7	"	"	"				
8	"	"	"				
9	"	"	"				
10	"	"	"				
11	"	"	"				
12	8:50	12731.6					
13	10:30	12780.1					
14	11:00	12802.8					
15	8:15	12810.0					
16	8:40	12814.6					
17	Readings not taken - house unoccupied						
18	"	"	"	"	"		
19	"	"	"	"	"		
20	"	"	"	"	"		
21	8:30	13103.3					
22	8:05	13160.8	- disconnected one 5 kW element to reduce cycling				
23	8:00	13218.1					
24	-	-			1654.0	38259	HH turned on. Speed 5
	8:30	13219.3		-	1656.75	38270	
25	8:15	13219.5		-	1660.0	38294	
26	10:00	13219.6			1662.1	38305	
27	9:45	13219.9		-	1665.2	38330	
28	7:50	13220.1		-	1667.75	38347	
29	8:00	13220.7		-	1672.75	38408	
30	8:30	13221.2		-	1677.4	38455	Ignition unreliable -
31	8:10	13221.6		-	1681.2	38504	many stops/starts!

NOTE: Data acquisition system not operational - start/stop circuitry under development - internal clock circuitry being debugged.

NOVEMBER 1985

DAY	TIME	CHROMALOX kW.h elec	WOOD STOVE lbs	HEAT kW.h elec	HARVESTER Monitor hrs	SPACE kW.h therm	COMMENTS
1	8:30	13222.0		1189.5	1685.25	38545	
2	10:30	13222.5		1191.4	1689.0	38584	
3	9:35	13222.7		1193.0	1692.1	38611	
4	8:00	13222.8	yes	1194.5	1694.6	38622	
5	8:10	13223.1		1195.0	1697.55	38650	
6	8:30	13223.2		1196.0	1699.5	38659	
7	6:40	13223.4		1198.1	1701.6	38670	
8	8:00	13223.6		1200.1	1705.15	38698	
9	8:05	13223.7		1201.3	1707.25	38711	
10	11:00	13224.1	yes	1203.8	1712.15	38753	
11	10:10	13224.6	yes	1205.8	1716.05	38807	
12	7:45		yes	1207.3	1718.85	38839	
13	8:00	13225.4	yes	1209.6	1723.0	38886	
14	8:00	13225.5		1210.6	1724.95	38898	to 38938 ISTA changed
15	8:00	13226.0		1212.7	1729.0	31107	to 31115 for calibrn
16	8:30	13226.7		1215.4	1734.3	31182	
17	12:00	13228.0		1218.5	1740.35	31275	
18	8:00	13228.3	52.0	1219.9	1743.0	31297	
19	8:30	13228.6	41.0	1221.4	1745.75	31329	
20	8:00	13228.8	40.0	1222.4	1747.8	31344	
21	8:00	13228.8		1223.3	1749.3	31344	
22	7:50	13229.3		1225.4	1753.2	31387	TB1 set 480F/ign fails
23	8:20	13229.9		1227.8	1757.75	31444	
24	8:00	13230.3	73.75	1229.6	1761.3	31475	D/A system on - temp
25	7:55	13230.6	47.5	1231.3	1764.7	31504	and TTL only
26	-	electric heat used - operator in Toronto					
27	-	"	-		"		
28	-	"	-		"		
29	8:00	13609.4		1232.3	1764.7	31564	HH restarted
30	9:50	13610.7		1236.7	1773.3	31678	
31	10:00	13611.0	77.75	1238.4	1776.6	31707	

NOTE: Nov. 1 to 23 - data acquisition system not available (removed for modification of circuitry) therefore system performance relative to ignition cycling not known.

DECEMBER 1985

DAY	TIME	CHROMALOX kW.h elec	WOOD STOVE lbs	HEAT kW.h elec	HARVESTER Monitor hrs	SPACE kW.h therm	DOM HOT kW.h Therm	WATER cubic metres
1	10:00	13611.0	77.75	1238.4	1776.65	31707		
2	8:00	13611.0	78.25	12391.1	1778.0	31713		
3	8:00	13611.3	58.5	1241.0	1781.65	31743		
4	8:00	13611.6	84.25	1242.9	1785.4	31774		
	22:00	ignition cycling			1789.65	cleaned combustion chamber		
5	8:00	13612.6		1246.2	1791.95	31865		
6	7:45	13613.7		1249.6	1798.4	31951	ignition cycling	
7	11:05	13615.5		1253.7	1806.1	32070	"	"
8	11:05	13616.0	69.25	1255.9	1810.25	32113	40152	392.592
9	8:00	13616.6		1259.5	1817.1	32164	40164	393.133
10	7:25	13617.6		1263.1	1824.2	32242	40179	393.330
		drive chains skipping on sprocket teeth occasionally						
	22:00	TB1 (ignition) cycling - hot fire - duct at orange heat						
11	7:55	13618.8		1267.1	1832.55	32316	40220	393.990
		TB1 tripped off in mid-operation - chains skipping						
12	8:15	13620.2		1270.8	1840.05	32390	40253	394.326
13	7:30	13621.4		1273.9	1846.15	32452	40273	394.600
14	11:40	13622.6		1278.0	1854.75	32541	40312	395.112
15	9:20	13623.0	87.25	1280.0	1858.6	32575	40335	395.410
		TB1 cycling during an apparently satisfactory burn						
16	7:45	13623.5	82.0	1281.8	1862.2	32618	40335	395.410
17	7:50	13624.5		1284.8	1868.1	32702	40335	395.410 DHW
18	8:00	13625.7		1287.7	1874.45	32804	40335	395.410 off
		TB1 cycling - ignition failure - comb chamber clogged/cleaned - 4 kg caked ash from comb. chamber - 4 kg ash in collection system - 3.3 kg ash in boiler ash pit						
		cracks found in welds in comb. chamber wall						
19	7:50	13666.5	105.75	1289.1	1877.7	32851		
		TB1 cycling						
20	8:20	13668.4		1292.4	1886.55	32979		
21	9:05	13670.5		1296.1	1896.55	33123		
22	10:00	13672.3		1299.1	1905.0	33247		
23	9:45	13673.2	64.75	1301.0	1910.2	33318		
24	8:50	13674.4		1303.4	1916.95	33411		
25	9:05	13676.8		1305.7	1923.2	33511		
		TB1 cycling - see D/A system output in Appendix XI						
26	10:20	13677.7		1307.6	1928.65	33579		
27	8:40	13679.7		1309.7	1934.2	33680		
28	8:00	13680.7	54.25	1311.7	1939.7	33749		
29	10:15	13681.6	48.75	1313.4	1944.7	33828		
30	7:30	13683.1		1315.6	1950.35	33912		
31	2:40	Heat Harvester failed - automatic transfer to Chromalox						
	8:30	13720.3	23.0	1317.4	1955.2	33985		

JANUARY 1986

DAY	TIME	CHROMALOX kW.h elec	WOOD STOVE lbs	HEAT kW.h elec	HARVESTER Monitor hrs	SPACE kW.h therm	DOM HOT kW.h therm	WATER cubic metres
1	10:00	13720.8	41.25	1318.9	1959.65	34027		
2	7:45	13725.2		1320.9	1964.9	34093		
		Hopper empty - automatic transfer to electric heat						
3	8:20	13744.5		1322.5	1969.45	34168		
4	9:30	13746.4		1325.7	1978.3	34284		
5	9:15	13747.4	43.25	1327.7	1983.95	34359		
6	7:20	13748.3	42.25	1329.7	1989.4	34437		
		Light smoke in boiler room - ash plugging exit from combustion chamber - ash removed - noticed auger flights burned - auger drive chains unusually taught						
7	7:40	13777.8		1331.3	1993.8	34502		
8	8:00	13779.3		1334.3	2001.8	34626		
9	8:00	13781.0		1337.1	2009.95	34747		
		Call-for-heat pilot light burned out - replaced						
10	7:45	13782.7		1338.8	2014.9	34822		
11	8:30	13783.1	31.0	1340.0	2018.3	34856		
12	9:00	13783.6	75.25	1342.7	2025.4	34910	40335	395.410
13	8:00	13783.9	49.0	1345.2	2032.0	34923	40372	395.838
14	13824.0			1346.9	2036.2	34938	40378	396.024
		Heat Harvester auger drive jammed - automatic transfer to Chromalox for space heating						
15	8:05	13997.8		1346.9	2036.2	34956		
16	7:50	14191.2		1346.9	"	34972		
17	8:00	14322.1	17.25	1347.0	"	34985		
18	8:50	14450.0		1347.1	"	34998		
19	10:20	14549.4		1347.15	"	35006		
20	7:50	14562.6	56.0	1347.3	"	35008		
21	7:50	14624.5		1347.4	"	35013		
22	8:55	14718.6		1347.6	"	35023		
23	8:20	14787.6	57.5	1347.8	"	35030		
		Heat Harvester auger drive motor output gear failed replacement parts ordered (manufacturer out of stock)						
24	8:00	14865.2	70.0	1347.85	"	35033		
25	10:00	15006.6	46.25	"	"	35041		
26	9:40	1512.4	53.25	"	"	35050		
27	9:00	15150.0	66.75	"	"	35051		
28	7:40	15169.1	35.5	"	"	35051		
29	7:50	15307.9		"	"	-		
	drive chain skipping - comb. chamber full of unburned chips							
30	7:40	15439.0		"	"	-		
31	7:40	15598.6		"	"	35087		

NOTE: Heat Harvester inoperable FEBRUARY and MARCH, 1986 - awaiting replacement parts.

APRIL 1986

DAY	TIME	CHROMALOX kW.h elec	WOOD STOVE lbs	HEAT kW.h elec	HARVESTER Monitor hrs	SPACE kW.h therm	COMMENTS
1	7:50	22207.2	34.75				
2	7:40	22212.4					
3	7:45	22251.3					
4	7:50	22306.4					
5	9:50	22375.6					
6	8:15	22467.8					
7	8:20	22536.7					
8	8:20	22641.3					
9	8:00	22726.3					
10	Missed	reading					
11	7:40	22887.5					
12	10:25	22944.1					
13	9:30	23019.7					
14	8:10	23054.8	46.0				
15	7:55	23099.9					
	19:30				2037.15	- Heat Harvester turned on	
16	7:40	23107.5		1349.0	2038.65	35840	
17	7:40	23107.5		1349.7	2039.95	35840	
18	7:20	23107.7		1350.7	2042.1	35857	
19	9:10	23107.9		1351.9	2044.6	35883	
20	8:50	23108.4		1353.6	2048.2	35925	
21	7:50	23108.6		1354.9	2051.0	35945	
22	8:25	23109.5		1356.6	2054.65	35985	
23	7:45	23109.9		1358.0	2057.5	36017	Trf to Chromalox
24	9:05	23122.5		1359.5	2060.3	36045	HH off while stoker
25	8:00	23175.6		1359.6	2060.3	36052	auger rebuilt with
26	9:20	23225.9		1359.8	2060.3	36057	stnless steel flights
27	11:00	23234.0	12.25	1360.6	2061.45	36058	Trf to HH
28	6:35	23234.1	20.25	1361.3	2062.95	36061	
29	7:10	23234.2		1362.5	2065.6	36070	
30	7:10	23234.3		1363.7	2068.25	36080	

MAY 1986

DAY	TIME	CHROMALOX	WOOD	HEAT HARVESTER		SPACE	COMMENTS
		kW.h elec	STOVE lbs	kW.h elec	Monitor hrs	kW.h therm	
1	7:20	23234.4		1364.9	2070.85	36096	
2	7:25	23234.4		1365.6	2072.6	36098	
3	8:00	23234.4	27.0	1366.4	2074.4	36098	
4	8:30	23234.4	43.75	1367.2	2076.3	36098	
5	7:30	23234.4	50.75	1367.9	2078.1	36098	
	Hopper empty - automatic transfer to Chromalox electric boiler						
6	7:05	23244.0		1368.8	2079.65	36115	
7	7:50	23279.7		1369.0	2079.65	38670	
8	7:20	23311.8		1369.4	2079.65	36122	
9	7:35	23341.8		1369.6	2079.65	36125	
10	9:00	23360.0		1369.9	2079.65	36128	
11	9:00	23401.8		1370.1	2079.65	36131	
12	6:55	23430.3		1370.4	2079.65	36133	
13	Heating system turned off - no requirement for space heat						
14							
15							
16							
17							
18	9:00	23464.9 - Chromalox on to heat rec room (visitors)					
19	Heating system turned off						
20							
21							
22							
23							
24							
25	9:20	23595.1		1371.0			
26	7:30	23609.1		1371.3			
27	8:00	23610.5		1371.4			
28	Heating system turned off - Heat Harvester disconnected						
29							
30	Vallsta stoker connected to CTC boiler						
31	Vallsta stoker fired - Cris Eyram, BDR Machinery, technical visit						

APPENDIX IX

INSTRUMENT/SENSOR CALIBRATION

WATER METER CALIBRATION

METER LOCATION	Electric DHW heating tank
SERIAL NO.	23217317
EMAC PORT	12

WATER COLLECTION CONTAINER WEIGHT 5.25 lb

EMAC COUNTS	- start	590	632	683	
	- stop	632	683	728	
	- counts	42	51	45	
METER READING	- start	664.7235	664.7755	664.842	cu m
	- stop	664.7755	664.842	664.899	cu m
	- total	.0052	.0665	.057	cu m
WEIGHT WATER COLLECTED	- gross	122.75	147.5	131.75	lbs
	- net	117.5	142.25	126.5	lbs
TIME TO COLLECT WATER		123.0	147.7	-	secs
VOLUME COLLECTED calculated from measured weight		11.75	14.225	12.65	Imp gall
		13.99	17.08	15.19	US gall
		52.95	64.67	57.51	litres
EMAC - litres/count		1.261	1.268	1.278	AVERAGE = 1.269

Rho-Sigma performance was checked during water meter calibration. Its totalizing water flow meter transducer is plumbed in series with the water meter and so could be tested at the same time.

RHO-SIGMA READING US gall	- start	523,646	523,660	523,677	US gall
	- stop	523,660	523,677	523,692	US gall
	- total	14	17	15	US gall
ERROR RELATIVE TO VOLUME COLLECTED		0%	0%	0%	

WATER METER CALIBRATION

METER LOCATION CTC boiler - DHW heating coil
SERIAL NO. 23217309
EMAC PORT 5

WATER COLLECTION CONTAINER WEIGHT 5.25 lb

EMAC COUNTS	- start	465	500	529	
	- stop	499	528	570	
	- counts	34	28	41	
METER READING	- start	433.913	433.958	433.9945	cu m
	- stop	433.957	433.993	434.0475	cu m
	- total	.044	.035	.053	cu m
WEIGHT WATER COLLECTED	- gross	100.75	83.75	120.0	lbs
	- net	95.5	78.5	114.75	lbs
TIME TO COLLECT WATER		131.5	112.0	157.6	secs
VOLUME COLLECTED calculated from measured weight		9.55	7.85	11.475	Imp gall
		-	-	-	US gall
		43.42	35.69	52.17	litres
EMAC - litres/count		1.277	1.275	1.272	AVERAGE = 1.275

APPENDIX X

LIST OF SENSORS - DATA ACQUISITION SYSTEM

REVISED 86 01 27

HEAT HARVESTER TB500H with CTC 453B HOT WATER BOILER
280 Wright Street, Fredericton, N.B.
1985-86 Heating Season

NUMBERS REFER TO SOCKET (PORT) NUMBERS ON THE E-MAC DATA LOGGER AND THEREFORE TO THE POSITIONS IN WHICH DATA APPEARS WHEN DISPLAYED OR PRINTED.

ANALOGUE

1 Temperature - CTC boiler DHW cold inlet
2 Temperature - CTC boiler DHW hot outlet
3 Temperature - CTC boiler heating loop inlet (bundle at junction board)
4 Temperature - CTC boiler heating loop outlet (bundle at junction board)
5 Temperature - electric DHW outlet
6 Temperature - electric DHW inlet
7 Temperature - NOT CONNECTED - stack gas when sensor fabricated
8 Temperature - NOT CONNECTED - CTC-to-Heat Harvester connecting duct
9 Temperature - garage (boiler room) air
10 Temperature - outdoor air at chip bin soffit
11 Temperature - living room thermostat
12 Temperature - bedroom thermostat
13 Temperature - recreation room thermostat
14 Temperature - CTC boiler jacket side panel
15 Temperature - HH TB500H combustion chamber side panel
16 Insolation meter - NOT CONNECTED - sunshine

PULSE

1 Start/stop - combustion system auger
2 Start/stop - combustion system igniter
3 Start/stop - circulating pump
4 Start/stop - electric hot water boiler (Chromalox)
5 Water quantity - CTC-HH DHW (1.275 litres/count)
6 CHANNEL FAULTY IN DATA LOGGER - NOT USED
7 kW.h thermal (ISTA) - CTC-HH space heating (100 pulses/kW.h)
8 kW.h electric - HH system (Kh = 2/3)
9 kW.h thermal (Rho Sigma) - electric DHW (1 pulse = 1000 Btu)
10 kW.h electric - Chromalox space heating & circulating pump (kH = 6)
11 kW.h thermal (ISTA) - electric DHW - NOT USED:NO ISTA AVAILABLE - see channel 9 - Rho-Sigma
12 Water quantity - electric DHW (1.269 litres/count)
13 NOT USED
14 kW.h thermal (ISTA) - CTC-HH DHW (100 pulses/kW.h)
15 kW.h electric - electric DHW (Kh = 6)
16 NOT USED

APPENDIX XI

TYPICAL DATA ACQUISITION SYSTEM OUTPUT

TYPICAL DATA ACQUISITION SYSTEM OUTPUT AS PRINTED

```
9985122500000000
   27.8   55.5   64.1   73.4   47.6   12.1  999.9  999.9
   24.2  -01.7   22.5   21.5   21.3   33.6   31.3  999.9
 016928 033694 040429 044322 029551 005917 059940 059940
 014443 001162 013625 013107 012784 019657 020211 059940
 019356 004365 053995 000001 000000 000000 000253 000201
 000020 000019 000000 000091 000000 000000 000617 000000
 113811 213814 204013 214118 204139 104159 114200 104202 114203 214204
 104229 204229 114230 104254 114256 214256 204321 214347 204408 214429
 104452 204452 114453 214526 204554 104634 114635 214635 104655 204655
 114656 214800 204814
```

EXPLANATION

```
Row                           Column Number
         1        2        3        4        5        6        7        8
1     998512250000000
2       27.8     55.5     64.1     73.4     47.6     12.1    999.9    999.9
3       24.2    -01.7     22.5     21.5     21.3     33.6     31.3    999.9
4     016928   033694   040429   044322   029551   005917   059940   059940
5     014443   001162   013625   013107   012784   019657   020211   059940
6     019356   004365   053995   000001   000000   000000   000253   000201
7     000020   000019   000000   000091   000000   000000   000617   000000
8     113811   213814   204013   214118   204139   104159   114200   104202   114203   214204
9     104452   204452   114453   214526   204554   104634   114635   214635   104655   204655
10    114656   214800   204814
```

Row 1 indicates the data logger number (99) and the date-time when the information was printed, in this case 85 12 25 00, or 1985 December 25th at 00:00 hours (ie midnight of Dec 24th).

Rows 2 and 3 show the actual analogue (temperature) sensor readings at the time of printing. Row 2 contains sensors 1 to 8, and row 3 sensors 9 to 16. For example, row 2 - col 3 indicates that sensor No. 3 read a temperature of 64.1C; this sensor is (from Appendix X) water entering the boiler from the space heating circuit. Row 2 - col 3 indicates that sensor No. 10 read -1.7C, the outdoor air temperature. The readings of 999.9C are from sensor positions 7, 8 and 16 which were not connected; the readings recorded are clearly unreasonable and so can be detected and ignored during data processing.

Rows 4 and 5 contain the sum of all the readings taken at each minute during the hour prior to printing, with the decimal point not shown, but understood to exist immediately before the last digit. With the decimal point inserted, the resulting number can be divided by 60 to yield the average temperature over the preceding hour. Row 4 shows totals for sensors 1 to 8, and row 5 for sensors 9 to 16. For example, the average living room temperature (sensor No. 11) can be found by using the number from row 5 - col 3, 013625. This is treated as 01362.5 and is divided by 60 to yield 22.7C, a value slightly higher than the instantaneous value of 22.5C shown in row 3 - col 3.

Rows 6 and 7 contain the total number of counts or pulses obtained from the pulse (or TTL) devices connected to TTL ports 1 to 8 and 9 to 16 respectively. Row 6 columns 1 to 4 should be ignored because devices connected to ports 1 to 4 produce data used for start/stop time logging, and this information appears in rows 8 onwards. Row 6 - col 5 shows a count of 000000, and this indicates that the device connected to port No. 5, the water meter on the DHW coil in the CTC boiler, did not operate - in other words, no hot water was taken from that source. By contrast, the water meter fitted to the electric DHW heating tank and connected to port No. 12 (row 7 - col 4) reads 91 counts; at 1.269 litres/count, this indicates that

(91)(1.269) = 115.5 l of hot water were used.

Row 8 onwards shows the various start/stop events that occurred during the hour immediately preceding the time at which the data logger output was printed and recorded. In each number, the first digit indicates the device involved as listed in Appendix X. The second digit, if 1, indicates a start or if 0, a stop. The next two digits indicate the minute, and the final two digits the second at which the event took place. For example, in row 8 starting at col 1, the Heat Harvester fuel feed auger (device No. 1) started at 23:38:11 then turned off at 23:41:59 - turned on at 23:42:00 and off at 23:42:02 - turned on at 23:42:03 and off at 23:44:52 - on at 23:44:53 and off 23:46:34 - on at 23:46:35 and off at 23:46:55 - on at 23:46:56 and was still running when data was printed; it turned off at 00:12:33 as recorded in the data output at 85122501 (the following hour).

APPENDIX XII

INDEX OF SLIDES

(Included with copy no. 1 of report only)

LIST OF SLIDES

1.2.2 Major sub-assemblies

1 Heat Harvester fuel hopper and frame assembly

2 Heat Harvester auger and transmission assembly

3 Heat Harvester auger drive system

4 Heat Harvester combustion chamber air inlet port showing primary and secondary air dampers and forced draft fan mounting bracket

5 Heat Harvester forced draft fan

6 Heat Harvester control panel. Gray box mounted above top left corner of panel is the fuel feed running time monitor

7 Heat Harvester control panel - inside view

8 Fully assembled Heat Harvester connected to CTC boiler and shown during an emissions test run

1.3 Burner-to-boiler duct

9 CTC boiler modification to attach flange to combustion gas entry port

10 Stainless steel duct used to connect Heat Harvester output to CTC boiler. The galvanized steel container under the duct was used during preliminary tests as an ash receiver

1.4 Ash handling system - original and revised

11 Original flexible auger ash handling system using 28 rpm gear-motor and small diameter conduit. Noisy and prone to frequent jamming

12 Detail of original ash handling system connection to ash discharge port on Heat Harvester combustion chamber

13 Revised ash handling system using slow, variable speed (0 to 6.5 rpm) gear-motor and large diameter conduit. Texaco oil can (20 l) used as ash collector

1.6 Draft inducer

14 Induced draft fan

1.8.1 Data acquisition system

15 Holman Electronic Controls Ltd. data acquisition system

16 kW.h meter modified for use with data acquisition system shown during initial operational check. Yellow device contains light source and photocell and is aimed at rotating disc in meter to which a strip of black electrical tape has been attached

17 Water meter as modified for use with data acquisition system

1.8.3.3 Energy meter calibration

18 Calibration testing of energy meter

2.2 High-limit thermocouple mount

19 Heat Harvester combustion chamber with sheet steel cladding and insulation removed to gain access to high-limit thermocouple mount

20 Heat Harvester frame section being removed in order to accomodate revised high-limit thermocouple installation

21 Original (defective) high-limit thermocouple (top) and replacement, ceramic-insulated, thermocouples

22 Revised high-limit thermocouple mounting

2.3 Missing flights - stoker auger

23 Stoker auger as delivered - flights missing over portion within transfer box and shown alongside Heat Harvester to indicate approximate location within the system

24 Stoker auger as rebuilt

3.2 Fuel feed measurement

25 Fuel feed-rate measurement by diverting fuel at transfer box over a timed period

4.3.1/6.3.9.1/6.3.9.2 Ash accumulation in combustion chamber

26 Heat Harvester combustion chamber hot gas outlet congested by sintered ash. Note that ash discharge port is completely bridged over and ash is spilling into connecting duct (removed) between combustion chamber and boiler

27 Detail view of ash accumulation shown in previous slide

4.3.2 Burn back

28 Scorched paint at fuel input (supposedly cool) end of combustion chamber indicates relatively high surface temperatures developed due to repeated burn-back along incoming fuel after normal shut-down

4.3.5 Fire and hot auger flights

29 View through boiler and into Heat Harvester combustion chamber during combustion showing incandescent ash, combustion chamber wall and stoker auger flights

4.3.6 Failed flights on stoker auger

30 Stoker auger flights (of mild steel) damaged by exposure to high temperatures within combustion chamber

4.3.9 Rebuilt auger with extended, stainless steel flights

31 Stoker auger rebuilt using stainless steel flights and extended (centreless) to run through the length of the combustion chamber to convey ash to the ash discharge port

32 Tooth breakage on output gear of auger drive gearmotor due to high loads imposed by inability of damaged stoker auger to convey fuel into combustion chamber

5.2 Fuel handling system - bulk storage-to-hopper

33 Scraper chain system in bin. Scrapers seen lying on floor travel towards limit switches mounted over flexible auger at far end of bin.

34 Scraper chain variable speed drive motor and chain drive system.

35 Detail of limit switch system and infeed to flexible auger - viewed looking along bin in direction of scraper travel.

36 Detail of limit switch system and infeed to flexible auger - top view looking down from above switches and into flexible auger.

37 Plastic conduit used for flexible auger system.

38 Overall view of flexible auger system as arranged to feed the Heat Harvester combustion system.

39 Detail of flexible auger drive motor and reduction gear system.

40 Action of scraper chain moving over pile of chips. Note that the scraper is travelling towards the viewer and accumulating chips ahead of itself.

41 Detail of infeed to flexible auger showing flexible rubber hose (red) located inside auger helix to help prevent overloading the auger.

42 Level controls (circular devices), time switch (in beige housing) and latching relay (in grey housing) fitted to Skogma 077 stoker.

43 Overall view of flexible auger system installed on Skogma 077 stoker.

44 Upper level control (diaphragm switch type) viewed from inside stoker hopper.

6.3.2 Ignition element

45 Ignition element showing original element (failed) and replacement element under test prior to installation

6.3.5.2 Fire extinguishing system

46 Automatic fire extinguisher as provided with Heat Harvester. Note wood and velcro strap adapter as provided by appliance manufacturer and fitted at neck of extinguisher

47 Automatic water sprinkler head and adapter used to provide secure, tightly sealed, mechanical attachment of head to Heat Harvester. Top sprinkler has been used; replacement (which screws into bottom of the large, threaded, pipe fitting) is shown at bottom

48 Water reservoir (black plastic tank attached to Heat Harvester fuel hopper - not to be confused with heating system expansion tank which appears directly above the reservoir) used to supply sprinkler head

6.3.6 Fuel feed system

49 Poor fuel feed from Heat Harvester hopper - funnelling

50 Poor fuel feed from Heat Harvester hopper - bridging

51 Stirrers used to improve fuel flow to auger in hopper. Original (inadequate) stirrer shown at bottom. Stirrers as used (four per shaft) shown at top

52 Stirrers as fitted in Heat Harvester hopper - original and revised types

53 Stirrers as fitted in Heat Harvester hopper - revised design

54 Chain drive scheme used to operate fuel stirrer shafts. Drive is taken from a sprocket installed on a shaft extension welded to the end of the hopper auger shaft (bottom)

55 Damaged (bent) flights on hopper auger at point where auger exits fuel hopper

6.3.8.1 Combustion chamber failures

56 Circumferential crack at hot end of combustion chamber running from one side of ash discharge port, across top, and down to other side of port. Note short horizontal weld above port and across which the circumferential crack runs; this weld was made during an earlier combustion chamber repair

57 Combustion chamber buckling. Original 250 mm inside diameter is reduced to about 180 mm

6.3.8.2 Oxidation damage to heat-transfer shroud

58 Heat-transfer shroud (which projects into combustion chamber from fuel feed end, and through which the stoker auger runs) shows erosion damage around outer lip and also rust (reddish marks). Note ignition element on left of shroud

General interest

59 Overall view of house in which Heat Harvester was installed

60 Electric domestic hot water tank installed as a control and for back-up hot water supply. Note Rho-Sigma energy meter on wall to left of DHW tank, and kW.h and water meters to right of tank. An ISTA energy meter is shown (mounted between the two water meters) but was not used in this location during the Heat Harvester test program

61 Chromalox electric heating boiler used for back-up space heating. Note kW.h meter to right of boiler and ISTA energy meter just off the top left corner and below the expansion tank

62 Fuel production at UNB wood chip processing centre. Seasoned hardwood logs are supplied in 8 foot lengths

63 Fuel production process - showing chipping (Arvin chipper), screening (to remove oversized particles) and transfer (up belt conveyor) to drying bin

64 Lessard hay bale conveyor (an extension section is shown) based upon which a chip handling conveyor was made

65 Galvanized sheet steel as fitted to frame of Lessard conveyor

66 Modified Lessard conveyor as used to move chips from trailer or truck and into above-ground storage bin

LATE ADDITIONS - 5.2 Fuel handling system

67 Overall view of scraper chain system viewed through bin loading door

68 Flexible auger and plastic conduit. Note large clearance between auger outside diameter and conduit inside diameter

69 Flexible auger and plastic conduit - dimensions

70 Use of centreless auger permits operation of auger within curved conduit in order to convey material around various obstacles